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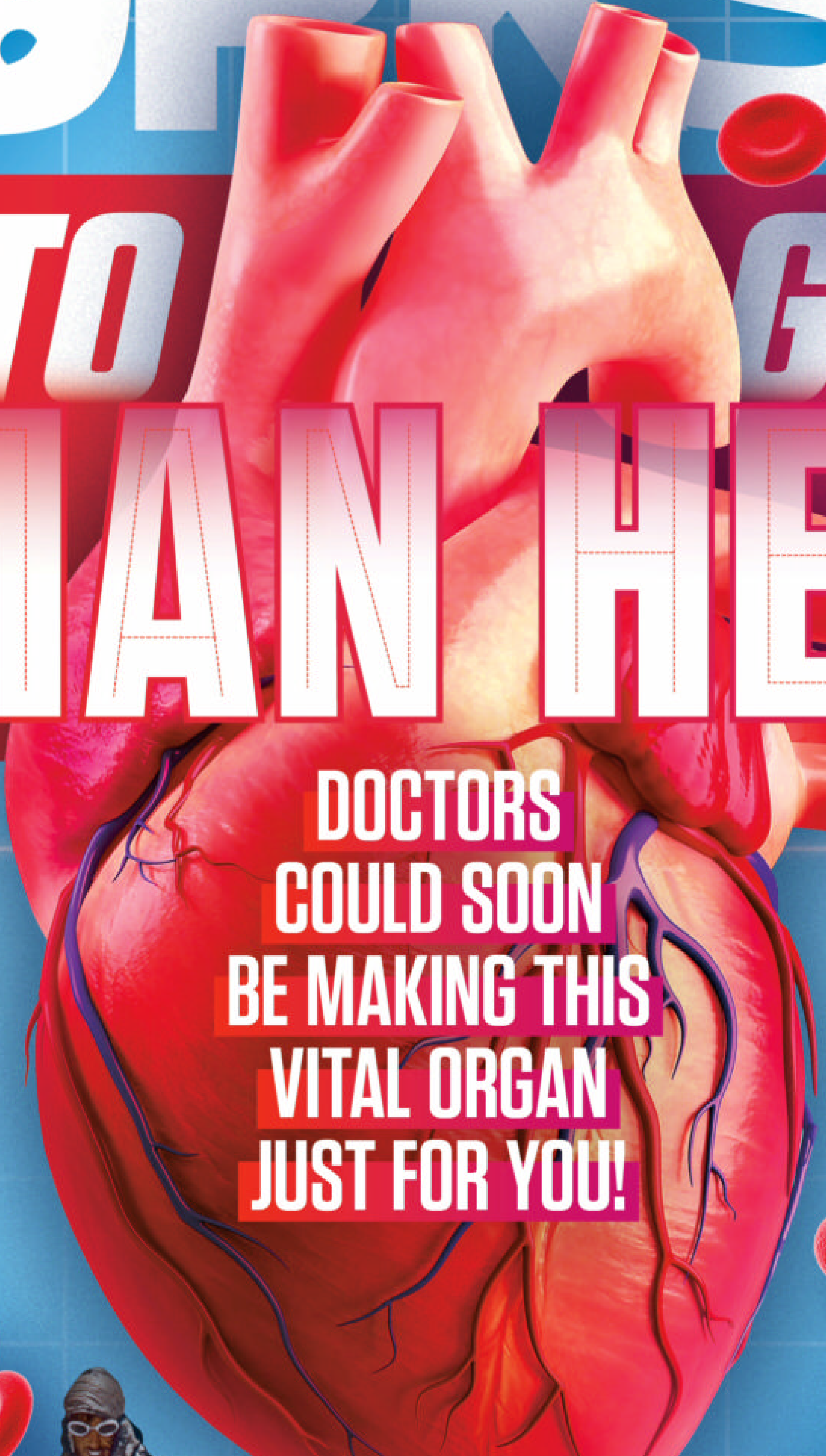

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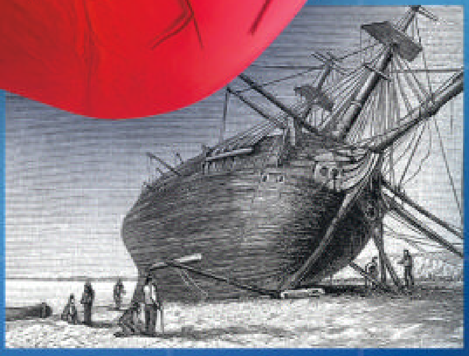

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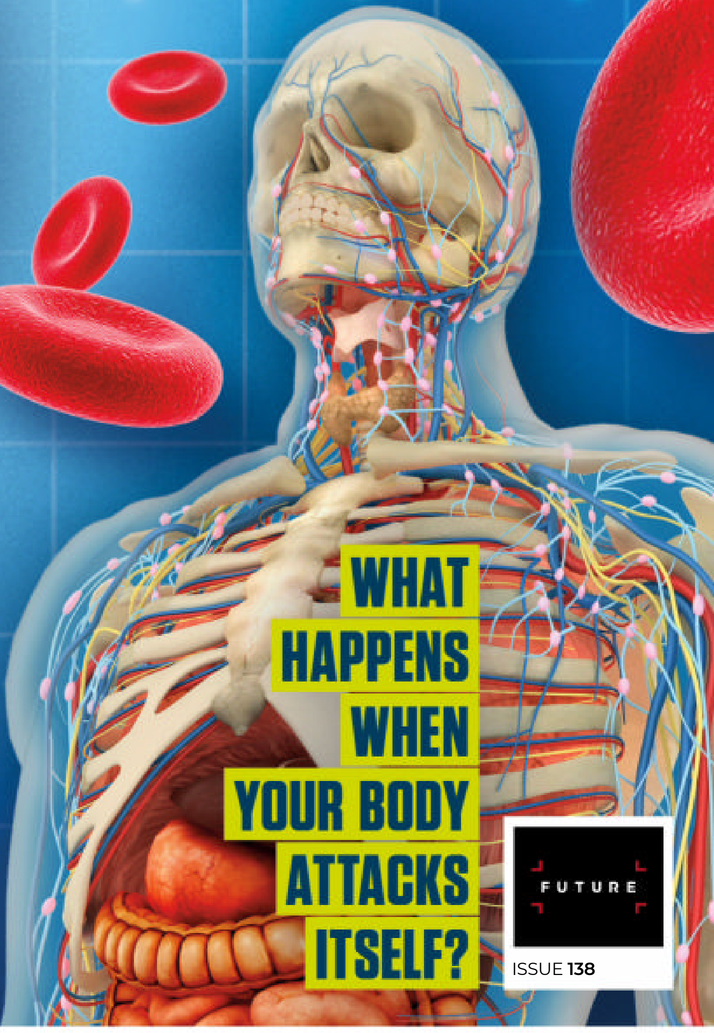

**WHAT HAPPENS WHEN YOUR BODY ATTACKS ITSELF?**

FUTURE

ISSUE 138

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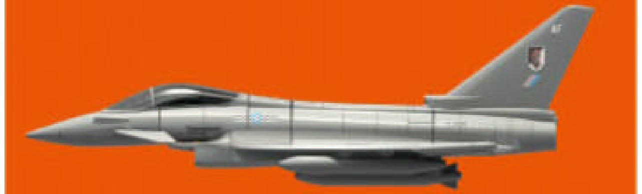
# QUICK BUILD

| | m | m |
|---|---|---|
| 1 | 14.12 | 9.25 |
| m² | kg | km/h |
| 22.60 | 7,123 | 1,065 |
| B km A | m/s | ↓ |
| 3,256 | 74.8 | 1.1 |

1 × Rolls-Royce Pegasus Mk. 105 vectored thrust turbofan



| | m | m |
|---|---|---|
| 1 | 15.96 | 10.95 |
| m² | kg | km/h |
| 51.20 | 11,15 | 2,475 |
| B km A | m/s | ↓ |
| 2,900 | 315 | 1.15 |

2 x Eurojet EJ200 Afterburning Turbofan

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The Eurofighter Typhoon is a twin-engine, canard–delta wing, multi-role fighter. It was designed originally as an air superiority fighter and is manufactured by a consortium of Airbus, BAE Systems and Leonardo. One of the world's most capable fighter aircraft, it possesses all the attributes that made the Spitfire so successful in combat and is the most effective air defence fighter to ever serve with the RAF.

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ISSUE 138

# WELCOME

The magazine that feeds minds!

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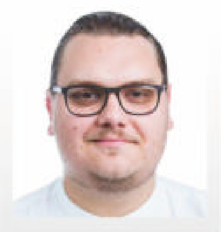
"The challenge is generating hundreds of billions of cells to make a heart"

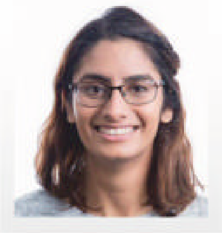
**Human heart: power pump, page 18**

## Meet the team…

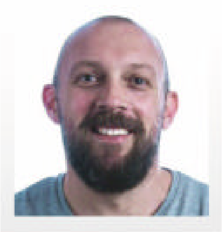
**Nikole**
**Production Editor**
We're constantly discovering strange phenomena in our vast universe. Learn about some of the weirdest over on page 60.



**Scott**
**Staff Writer**
Meet Earth's many primates and follow their 65-million-year evolutionary journey across the changing planet on page 38.



**Baljeet**
**Research Editor**
On page 28 we explore a variety of autoimmune diseases and how they affect and compromise the human body.



**Duncan**
**Senior Art Editor**
Would you modify your body with an implanted identity chip? Discover this and other cybernetic enhancements on page 66.

**Ailsa**
**Staff Writer**
Nearly 200 years ago, Charles Darwin set out on a voyage that would change how we view life on Earth. Follow his journey on page 46.

It might be one of the hardest working organs in the body, but most of us take our heart for granted as it beats thousands of times of day, pumping gallons of life-giving blood around our bodies. It's only when something goes wrong with your heart that you can truly appreciate how important it is. In this issue of **How It Works** we explore the function of this fist-sized ball of muscle in your chest and how its 'mini-brain' acts as an organic pacemaker to keep a steady rhythm. We've also spoken to a scientist whose research could mean that we'll be able to grow replacement hearts for human patients in the future. I hope you enjoy the issue.

**Ben** Editor

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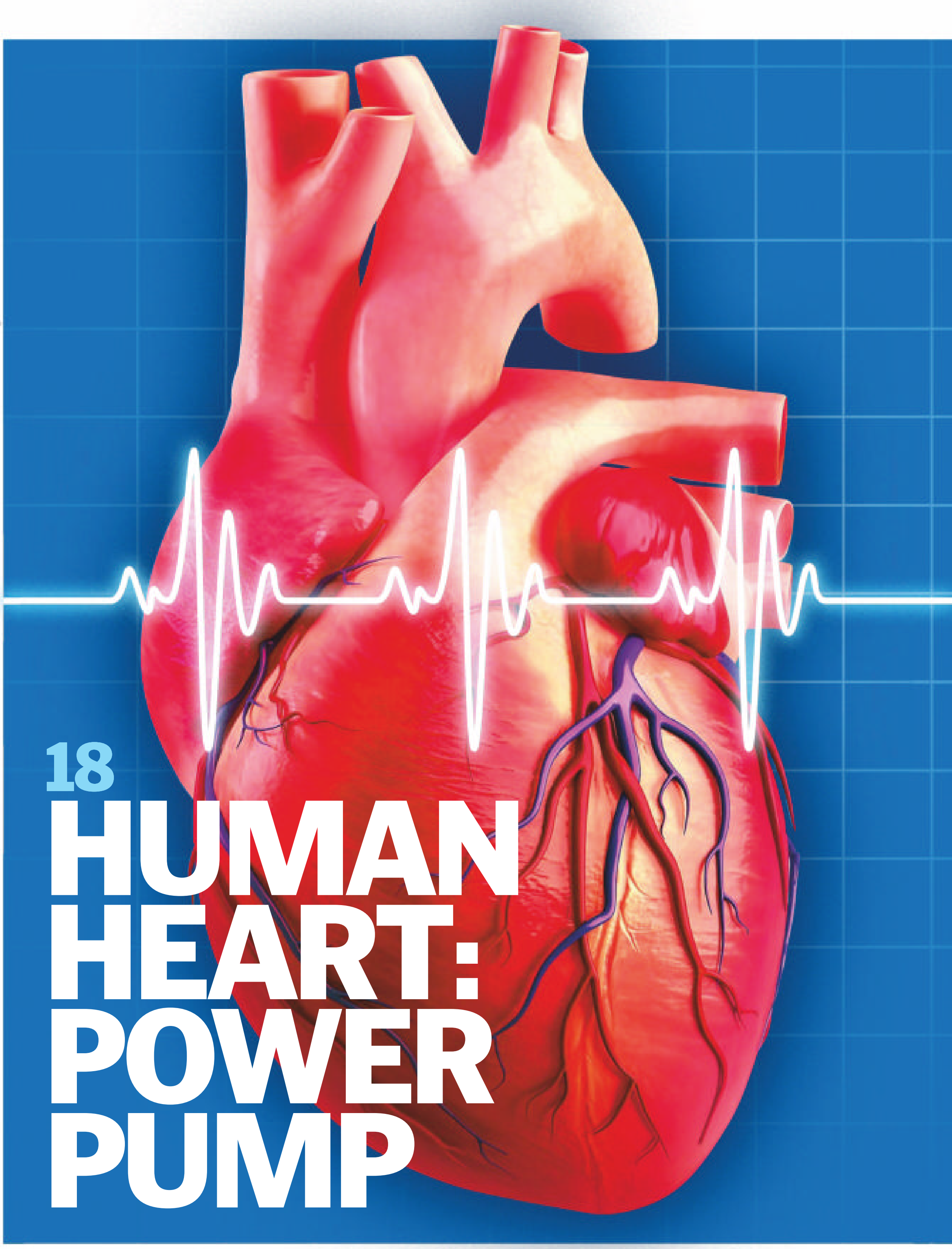

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After being launched by the QR code, the app reads anything you point your device's camera at 30 times a second, searching for distinctive shapes we've trained it to recognise. When it sees a familiar picture, it overlays the augmented-reality 3D image we've previously uploaded on your screen.

## MEET THIS ISSUE'S EXPERTS…

**Jo Elphick**
Jo is an academic lawyer and lecturer specialising in criminal law and forensics. She is also the author of a number of true crime books.

**Mark Smith**
A technology and multimedia specialist, Mark has written tech articles for leading online and print publications for many years.

**Andy Extance**
Andy is a freelance science writer based in Exeter, UK. He previously worked in early stage drug discovery research, followed by a brief stint in silicone adhesive and rubber manufacturing.

**Dr Andrew May**
Andrew has a PhD in astrophysics and 30 years in public and private industry. He enjoys space writing and is the author of several books.

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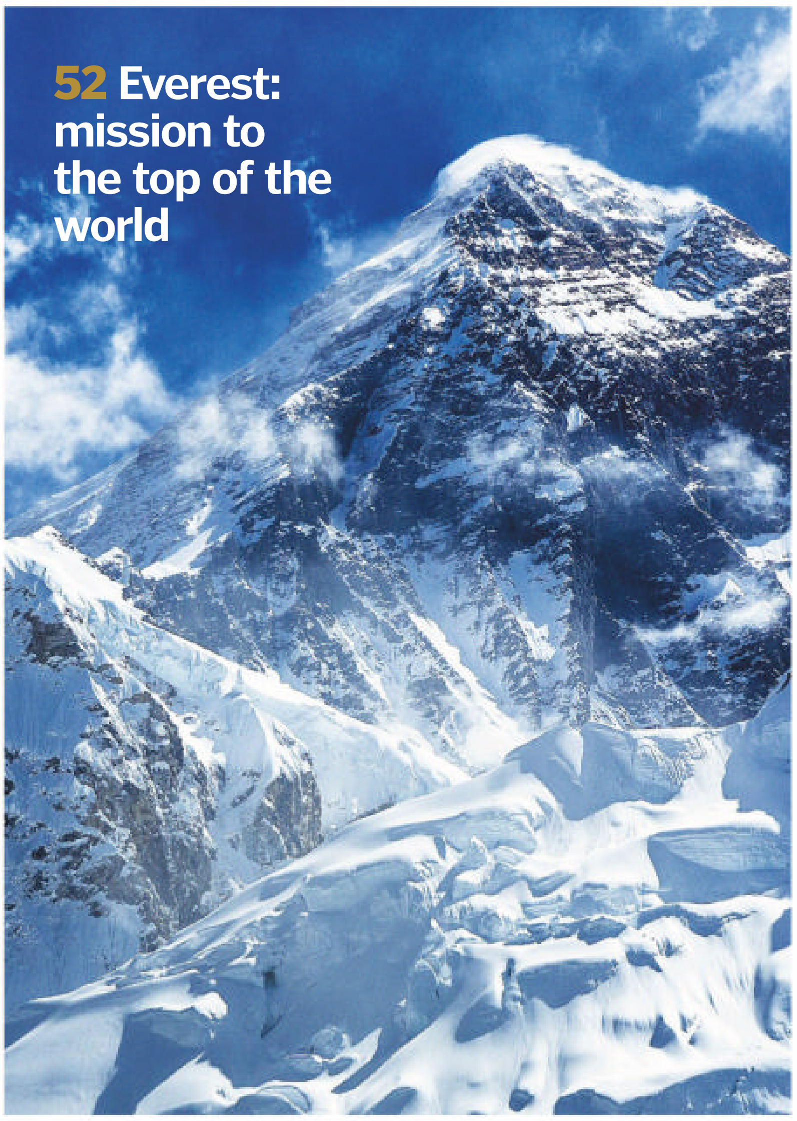

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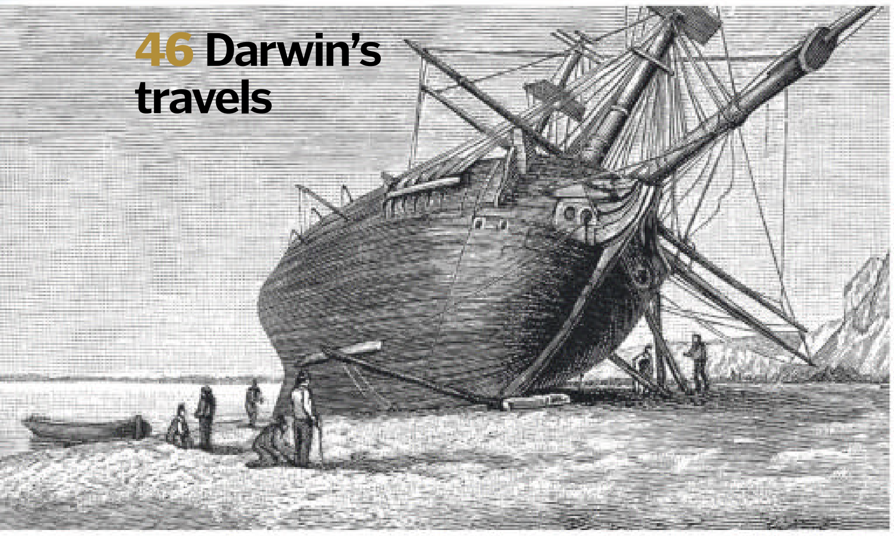

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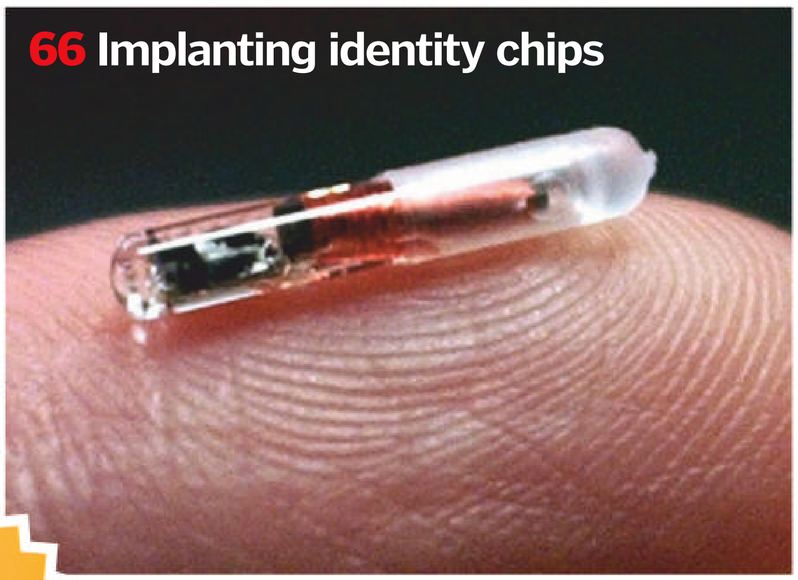

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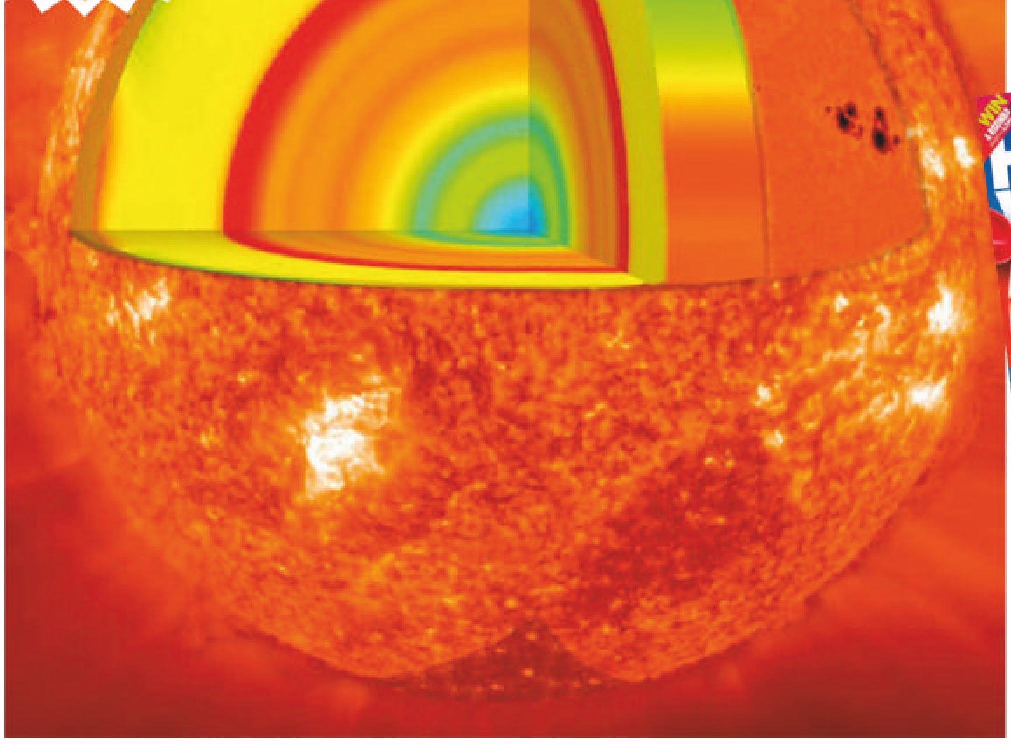

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## SUBSCRIBE NOW!

Go to page 26 for great deals

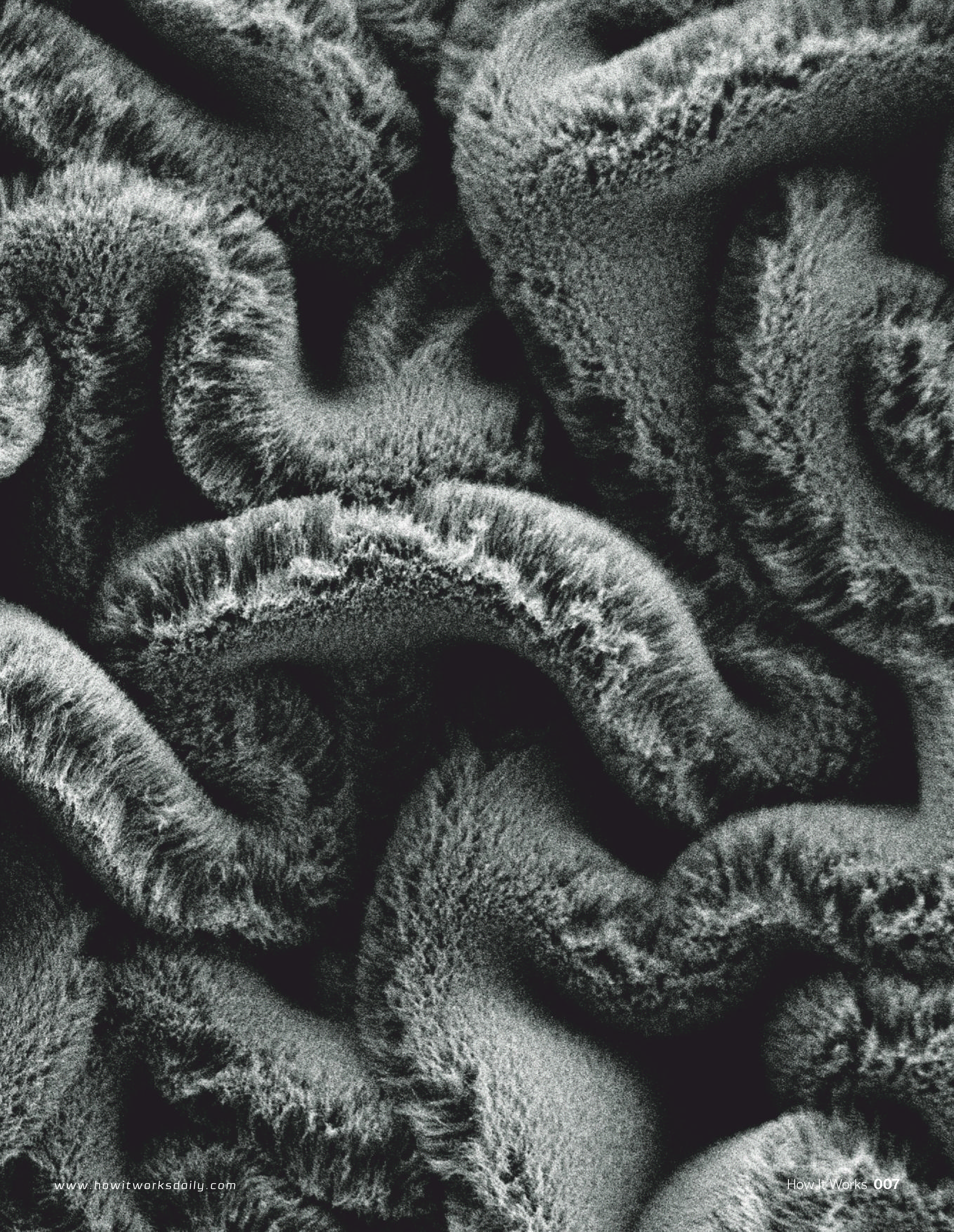
**Amy Grisdale**
Volunteer animal worker Amy has an enormous breadth of experience on animal conservation projects. She specialises in writing about environmental topics.

**Jack Parsons**
A self-confessed technophile, Jack has a keen interest in gadgets and wearable tech, but also loves to write about science projects with much grander ambitions.

## POWER-STORING SPAGHETTI

This image may just appear to be the folds of a cosy blanket, but it is in fact a forest of millions of nanotubes each only 20 to 30 micrometres tall. They all work together as a novel type of supercapacitor that has been engineered by researchers at both Duke University and Michigan State University in the US. A supercapacitor is a way to store energy like a battery does, but without using chemical energy for power production. Each nanotube supercapacitor patch is around the same size of a stamp and can carry more than two volts. The intention of these stretchable patches is to explore the possibility of future wearable technologies.

© Changyong Cao/Michigan State University



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# DANDELION SEED SPREADING

Plants have evolved various methods to spread themselves around the world. One innovative way is to take advantage of the wind. Ensuring their fruit travel further afield, individual seeds are designed to act as feathery parachutes to hitch a ride on the breeze. Each parachute is called a pappus, from the Greek word for grandfather, due to their resemblance to a white beard. Often dropping within a few metres of their mother plant, research has found that some seeds can travel over a kilometre before finally landing.

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SPACE

# Baby stars could destroy the 'Pillars of Creation'

Words by **Brandon Specktor**

Spearing the sky like monolithic elephant trunks, the Pillars of Creation are a vast star-forming region located in the Eagle Nebula, about 7,000 light years from Earth. These tendrils of gas and dust, made colourful by the radiation of bright young stars smouldering within, became a Milky Way landmark thanks to an iconic visible-light image taken by the Hubble Space Telescope in 1995.

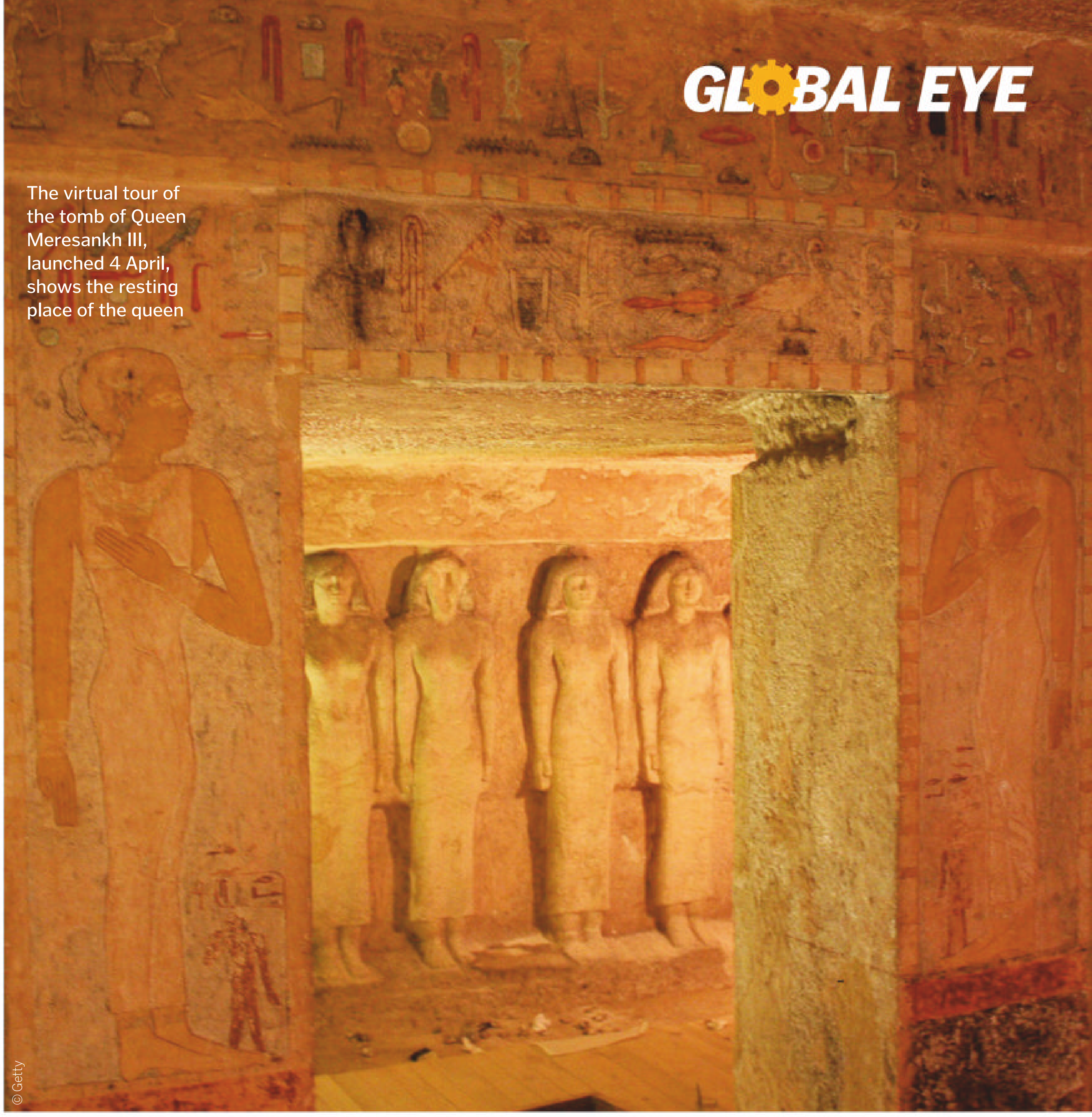
Now NASA scientists have shared a new view of the pillars, focusing instead on the infrared radiation normally invisible to human eyes. In the new image, also taken by the Hubble Space Telescope, the colourful pillars fade to ghosts of their former selves, revealing a kaleidoscope of newborn stars within the dust.

The pillars, which span about five light years in length – that's about 3.5 times the diameter of our Solar System – are natural incubators of star formation thanks to their many dense pockets of hydrogen gas. As ever greater quantities of gas and dust pile into a single gravitationally dense area, that area heats up under the weight of the gathering material and may turn into the seeds of a star, also called a 'protostar'. If a protostar continues gathering mass and increasing in temperature enough to spark a nuclear reaction at its core, a full-fledged star is born.

As this image shows, the most active star-forming region within the pillars is located at the tip of the largest pillar, which shimmers with what appears to be gauzy-blue radiation. These dense, dusty regions shadow and cool the gas below them, according to NASA, allowing the lower reaches of the pillars to maintain their long, wispy figures… for now anyway. According to NASA astronomer Paul Scowen, who led the initial Hubble exploration of the Eagle Nebula in 1995, as the stars at the tip of the pillars grow ever larger, their radiation will become stronger, slowly destroying the gas around them.

"The gaseous pillars are actually getting ionised, a process by which electrons are stripped off of atoms, and heated up by radiation from the massive stars," said Scowen. "The stars' strong winds and barrage of charged particles … are literally sandblasting away the tops of these pillars." Perhaps that makes images like this one even more special. We will never see the Pillars of Creation exactly like this ever again.

The iconic 'Pillars of Creation' glow anew in infrared light



The virtual tour of the tomb of Queen Meresankh III, launched 4 April, shows the resting place of the queen

© Getty

HISTORY

# Egypt offers virtual tours of ancient sites

Words by **Laura Geggel**

Virtual tours of a handful of Egypt's archaeological marvels, including the ancient tomb of Queen Meresankh III and the fourth-century Red Monastery, are now available online. If you're looking for a great way to 'explore' while stuck at home during the COVID-19 pandemic, this might be the perfect option. The 3D tours show the ancient Egyptian sites in stunning detail, allowing viewers to virtually 'walk through' different parts of the ruins, much like how the navigation on Google Street View works.

Egypt's Ministry of Tourism and Antiquities began posting the tours as a way to share these wonders with people who are staying at home to help 'flatten the curve' during the coronavirus pandemic, the Ministry announced on its Facebook page.

One of the tours currently on offer – the tomb of Menna – features "one of the most visited and best preserved" of the elite tombs from the 18th Dynasty of 1549 BCE to 1292 BCE, the Ministry of Tourism and Antiquities wrote in the statement. The tomb, located in the Theban Necropolis – now modern-day Luxor – is known for its well-preserved paintings.

Little is known about Menna, but his tomb offers clues about his life among Egypt's upper crust. Titles found in his tomb suggest he was a scribe who also oversaw the pharaoh's fields and the temple of Amun-Re, a form of the sun god.

"From the scenes depicted in his tomb we can see that Menna supervised delegations who measured the fields, brought defaulters to justice, inspected field work and recorded the yield of the crop," Melinda Hartwig, ARCE president emeritus, wrote in the book *The Tomb Chapel of Menna (TT 69): The Art, Culture, and Science of Painting in an Egyptian Tomb*.

All of these virtual tours "enable people worldwide to enjoy the ancient civilisation during their home confinement" as part of the measures "taken to fight coronavirus (COVID-19)," said the Ministry of Tourism and Antiquities.

An illustration of the temperate rainforest that thrived in West Antarctica when dinosaurs still walked the Earth

© J.McKay/Alfred-Wegener-Institut

PLANET EARTH

# Ancient rainforest found under Antarctic ice

Words by **Laura Geggel**

About 90 million years ago, West Antarctica was home to a thriving temperate rainforest, according to fossil roots, pollen and spores recently discovered there, a new study finds.

The world was a different place back then. During the middle of the Cretaceous Period, spanning 145 to 66 million years ago, dinosaurs roamed and sea levels were 170 metres higher than today. Sea-surface temperatures in the tropics were as hot as 35 degrees Celsius. This scorching climate allowed a rainforest, similar to those seen in New Zealand today, to take root in Antarctica.

The rainforest's remains were discovered under the ice in a sediment core that a team of international researchers collected from a seabed near Pine Island Glacier in West Antarctica in 2017.

When the team saw the core, they knew they had something unusual. The layer that formed 90 million years ago was a different colour. "It clearly differed from the layers above it," said lead researcher Johann Klages.

Back at the lab, the team put the core into a CT (computed tomography) scanner. The resulting digital image showed a dense network of roots throughout the entire soil layer. The dirt also revealed ancient pollen, spores and the remnants of flowering plants from the Cretaceous Period.

By analysing the pollen and spores, study co-researcher Ulrich Salzmann was able to reconstruct West Antarctica's 90 million-year-old vegetation and climate. "The numerous plant remains indicate that the coast of West Antarctica was, back then, a dense temperate, swampy forest, similar to the forests found in New Zealand today," said Salzmann.

The sediment core revealed that during the mid-Cretaceous West Antarctica had a mild climate, with an annual mean air temperature of about 12 degrees Celsius. Summer temperatures were warmer, with an average of 19 degrees Celsius. In rivers and swamps the water would have reached up to 20 degrees Celsius.

These temperatures are impressively warm given that Antarctica had a four-month polar night, meaning that a third of every year had no life-giving sunlight. However, the world as a whole was warmer back then, in part because the carbon dioxide concentration in the atmosphere was high – even higher than previously thought.

"Before our study the general assumption was that the global carbon dioxide concentration in the Cretaceous was roughly 1,000 parts per million (ppm)," says study co-researcher Gerrit Lohmann. "But in our model-based experiments it took concentration levels of 1,120 to 1,680 ppm to reach the average temperatures back then in the Antarctic."

These findings show how potent greenhouse gases like carbon dioxide can cause temperatures to skyrocket, so much so that today's freezing West Antarctica once hosted a rainforest. Moreover it shows how important the cooling effects of today's ice sheets are.

SPACE

# NASA funds telescope on the Moon's far side

Words by **Yasemin Saplakoglu**

NASA is funding an early stage proposal to build a meshed telescope inside a crater on the far side of the Moon. This 'dark side' is the face of the Moon that is permanently positioned away from Earth, and as such it offers a rare view of the dark cosmos, unhindered by radio interference from humans and by our planet's thick atmosphere.

The ultra-long-wavelength radio telescope would be dubbed the 'Lunar Crater Radio Telescope' and would have "tremendous" advantages compared to telescopes on our planet, said the idea's founder Saptarshi Bandyopadhyay, robotics technologist at NASA's Jet Propulsion Laboratory.

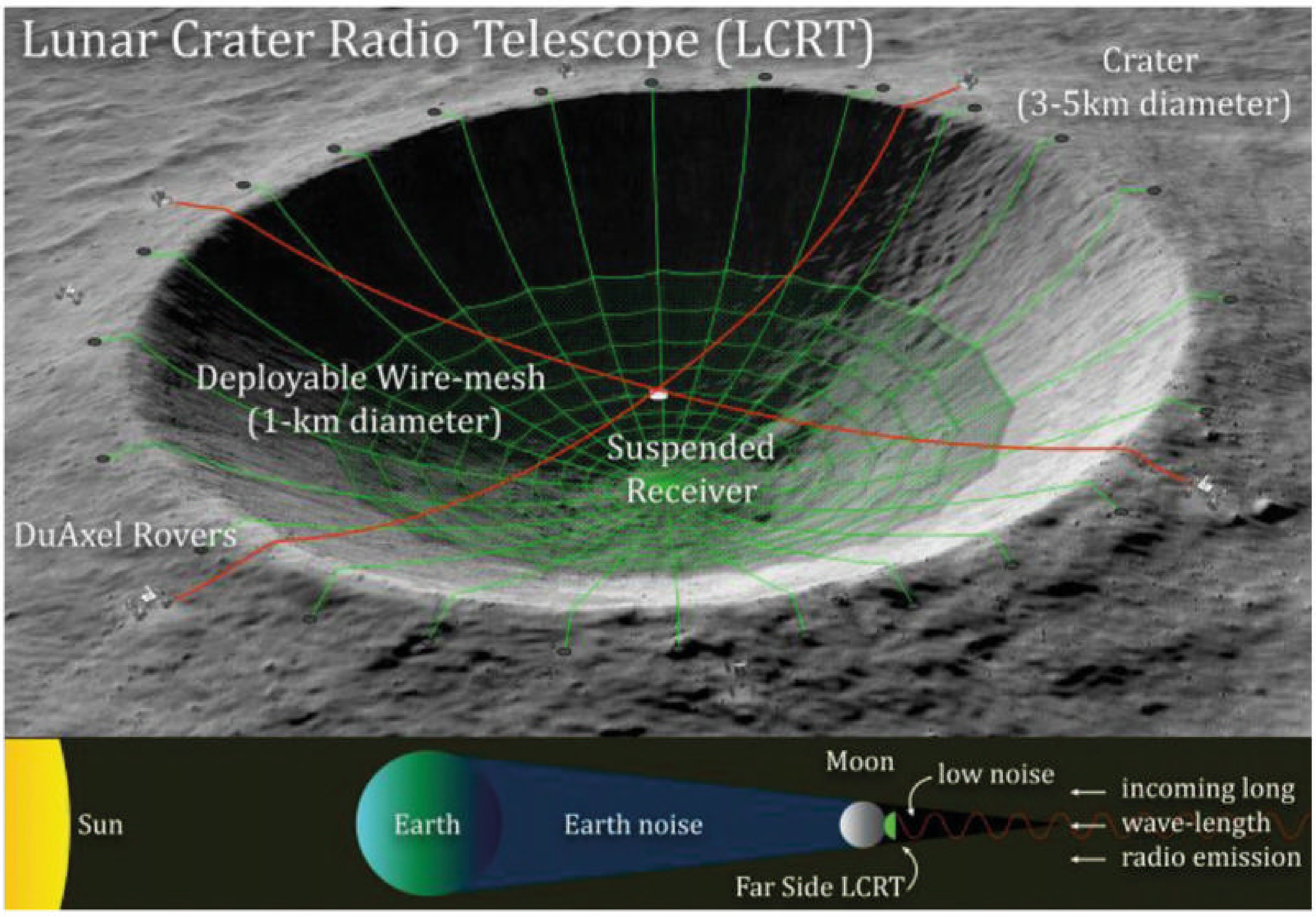
The NASA Innovative Advanced Concepts Program is awarding $125,000 (approx. £100,300) for a Phase 1 study to understand feasibility. The telescope, designed as a wire mesh, would be deployed into a three to five kilometre crater on the Moon's far side. The one-kilometre wire-mesh telescope would be stretched across the crater by NASA's DuAxel Rovers or wall-climbing robots, according to the proposal summary.

If it ends up being built the 'Lunar Crater Radio Telescope' would be the largest filled-aperture radio telescope in the entire Solar System. A filled-aperture radio telescope is a telescope that uses a single dish to collect data rather than using many dishes.

Because this telescope would be on the far side of the Moon, it would avoid any radio interference from Earth, satellites and even the Sun's radio noise during the lunar night. It would also let us gaze out into the cosmos without the veil of Earth's atmosphere.

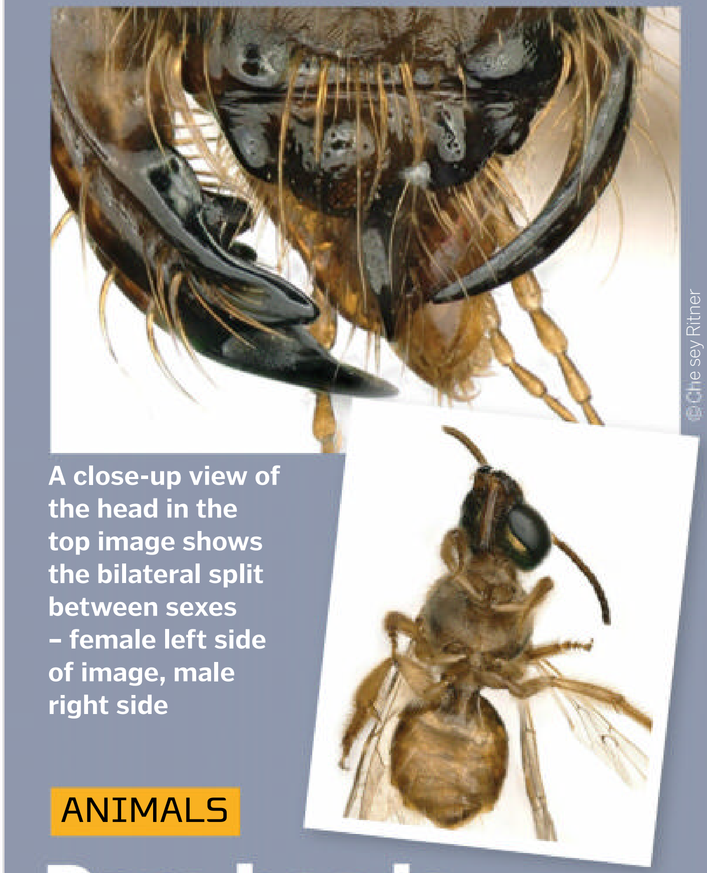
The atmosphere reflects low-frequency wavelengths of light greater than ten metres, essentially blocking them from reaching ground-based telescopes. The new lunar telescope "could enable tremendous scientific discoveries in the field of cosmology by observing the early universe in the 10 to 50 metre wavelength band … which has not been explored by humans."

> "It offers a rare view of the dark cosmos"



© Saptarsh Bandyopadhyay

**The proposed telescope would be a one-kilometre-diameter wire-mesh that can gaze out into the cosmos without being hindered by Earth's atmosphere**



© Chelsey Ritner

**A close-up view of the head in the top image shows the bilateral split between sexes – female left side of image, male right side**

ANIMALS

# Rare bee is half-male and half-female

Words by **Mindy Weisberger**

In an un-bee-lievable discovery, scientists identified a bee that's male on its left side and female on its right. The condition is known as gynandromorphy. Researchers found the bee inside a nest collected in Panama, in a forest on Barro Colorado Island. When the nest was collected the bee was a larva enclosed in a brood cell – a chamber in the honeycomb where young bees grow – and the scientists noticed that it was a gynandromorph when it emerged as an adult. This is the first known example in the bee species *Megalopta amoena* and is only the second such case found in the genus Megalopta, or sweat bees, in over 20 years of research.

On the bee's head, the 'female side' has a forward-facing antenna and a bigger, stronger mandible. The female side's hind leg is also larger and hairier than its counterpart on the male side. Hairs used for pollen collection cover the female half of the lower body while the male side of the body shows few hairs.

The bee is known as a bilateral gynandromorph due to its sex differences being divided right down the middle. Gynandromorphy may also be axial, in which the front of the body is one sex and the back is another. The condition can also appear as a mosaic, with male and female features mixed up and scattered around the animal's body, scientists reported in 2013.

ANIMALS

# 'Longest animal ever' discovered in Australian waters

Words by **Rafi Letzter**

Underwater explorers found a 45-metre siphonophore, a translucent, stringy creature that, like coral, is made up of smaller critters, living in a submarine canyon off the coast of Australia. It's "seemingly the largest animal ever discovered," they said.

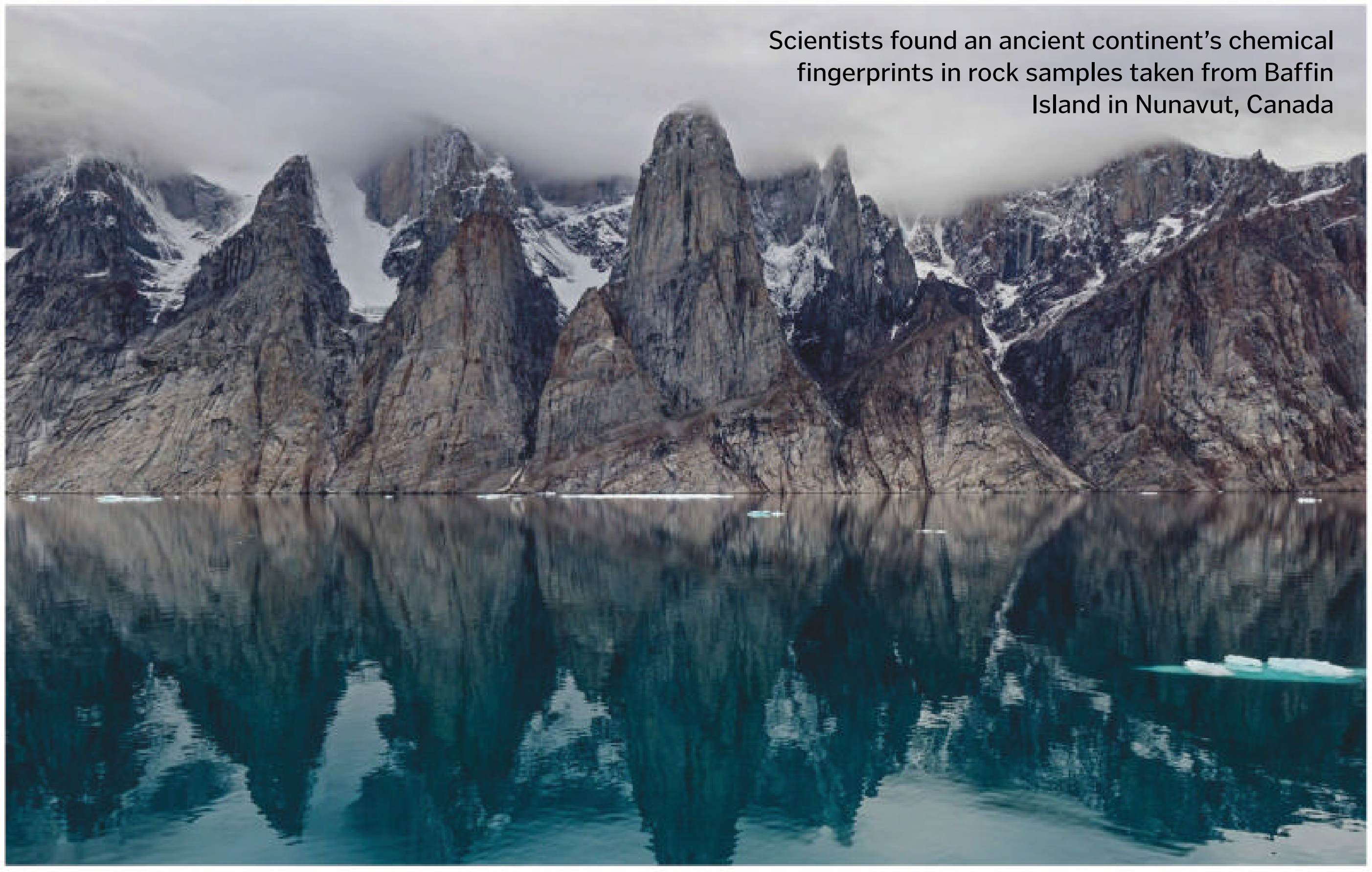
Every individual siphonophore is made up of many little 'zooids', each living lives that are more similar to animals we're used to talking about, albeit always connected to the larger colony. Zooids are born asexually, and each one performs a function for the siphonophore's larger body. Linked together in long chains, the colonies were already known to reach lengths of up to 40 metres.

The new record-setting siphonophore was one of several discoveries made by a team aboard the research vessel Falkor while exploring deep-sea canyons near Australia's Ningaloo Coast. The researchers used a remotely operated vehicle (ROV) called ROV SuBastian to explore and collect samples from deep-ocean areas that hadn't been investigated before. In March researchers using the same ROV discovered gardens and graveyards of coral in three submarine canyons off South Australia.

During this latest voyage through waters off western Australia the researchers also discovered large colonies of glass sponges and other species.

© Schmidt Ocean Institute

This image shows the coils of the long siphonophore off the coast of Australia



Scientists found an ancient continent's chemical fingerprints in rock samples taken from Baffin Island in Nunavut, Canada

© Getty

PLANET EARTH

# Piece of lost continent discovered beneath Canada

Words by **Mindy Weisberger**

A piece of a lost continent has been discovered lurking beneath Canada, and the evidence was hiding in rocks that originated in Earth's interior where diamonds form. The secret was concealed in a type of diamond-bearing volcanic rock known as kimberlite. Kimberlite originates deep underground in magma in Earth's mantle and picks up hitchhiking diamonds as it hurtles towards the surface during volcanic eruptions.

Scientists found that the mineral chemistry of the Baffin Island kimberlite matched that from an ancient and long-lost continent that formed nearly 3 billion years ago and broke up 150 million years ago.

Earth's land masses, or continents, didn't always look the way they do now. The first continents emerged when Earth was just a restless baby planet. These ancient and enormous rocky slabs, called cratons, then shattered to form smaller land masses.

For hundreds of millions of years plate tectonics pushed continents together to form giant supercontinents, only to pull them apart and push them together again. The last of the supercontinents, Pangaea, began to separate about 200 million years ago, and by around 60 million years ago the continents had split into the seven that we know today: Africa, Antarctica, Asia, Australia, Europe, North America and South America.

Though the planet's first continents fragmented and were lost to time, remnants of the long-lost land masses survive to this day as stable cores in our modern continents. The kimberlite samples from Baffin Island, which came from a depth of nearly 400 kilometres, bore chemical similarities to mantle rock samples from underneath part of the North Atlantic Craton in Greenland.

Under most remnants of ancient continents, the upper mantle contains about 65 per cent olivine, "the main mineral of the upper mantle," and about 25 per cent of another mineral called orthopyroxene, said lead study author Maya Kopylova, a geologist with the University of British Columbia in Canada. By comparison the mantle make-up under the North Atlantic Craton is about 85 per cent olivine and around ten per cent orthopyroxene. And the mineral ratio in the Baffin Island kimberlite was a close match to the North Atlantic Craton, Kopylova said.

Now scientists know "with certainty" that part of Baffin Island was at some point joined with the North Atlantic Craton "rather than with other ancient continents," said Kopylova.

ANIMALS

# ‘Mind-control’ cat parasite reaches Hawaii’s parks

Words by **Mindy Weisberger**

*Toxoplasma gondii*, a ‘mind-controlling’ parasite that causes the disease toxoplasmosis, has been found in public lands in Oahu, Hawaii, for the first time, researchers have discovered. Though this parasite was previously found in people and in wildlife on the Hawaiian islands, it was unknown in Oahu’s parks. It hitchhiked there in free-ranging cats, which are a non-native species and are known hosts of the parasite.

However, the cats aren’t really to blame; people are the ones who first brought cats to the island and then allowed them to roam free. Felines that were abandoned then bred in the wild and formed feral colonies. These cat communities now threaten to expose local wildlife to a harmful and potentially deadly parasite.

*Toxoplasma gondii* is transmitted from cats to other animals, including humans, when cats expel the parasite in faeces in capsule-like eggs, or oocysts. Once *T. gondii* oocysts enter a new host they transform into an actively multiplying form called tachyzoites, which can replicate so quickly that they overwhelm the host’s immune system and lead to serious health problems.

One of the ways that *Toxoplasma gondii* affects mice and rats is by tweaking their brain chemistry to change their behaviour. Rodents typically avoid cats, but under *T. gondii*’s ‘mind control’ they seek out felines. And that’s exactly what *T. gondii* wants, because the infected rats need to be ingested by cats in order for *T. gondii* to complete its life cycle.

Researchers recently looked for feral cat colonies and signs of *Toxoplasma gondii* at 32 locations in Oahu’s parks and public lands inhabited by native bird species. They identified 25 cat colonies near places where native birds were plentiful. The exact number of cats in each colony was uncertain, but the scientists spotted roughly 23 cats on average at every location. Humans were also feeding the cats at most of these colonies, evidence suggested.

The scientists also gathered 56 faecal samples from four of the cat colonies. Three out of four of those colonies had cats shedding *T. gondii*, with about ten per cent of the samples testing positive.

“The high percentage of *T. gondii*-positive faeces samples suggests that Oahu’s cats are contributing large quantities of this infectious parasite to parks and neighbourhoods across the island,” said study co-author Grant Sizemore, director of Invasive Species Programs at American Bird Conservancy. “What’s particularly worrying is that these hardy oocysts move through the environment with the potential to infect any warm-blooded species in terrestrial, freshwater or marine ecosystems,” he added.

As the team collected faeces at only four locations, it’s likely that *T. gondii* is even more widespread on Oahu ”and possibly other islands,” and poses an even greater threat to vulnerable native wildlife.

The parasite is carried and spread by domestic felines

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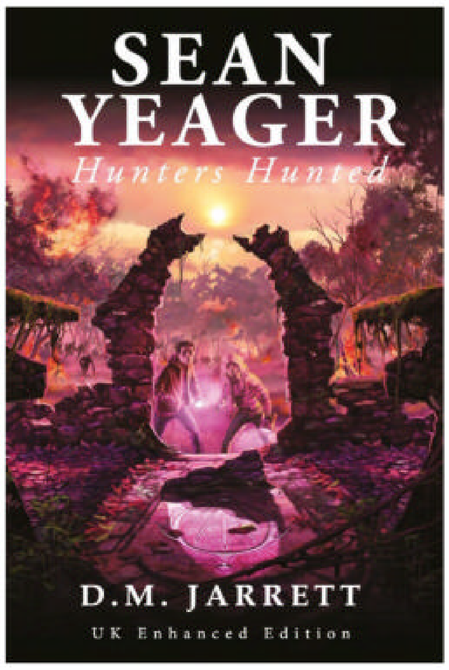

Intruder alert! Confirm your identity!

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# WISH LIST

## The latest **home hygiene** gadgets

© PhoneSoap

## PhoneSoap Pro

Price: **$119.95 (approx. £96.99)**
**www.phonesoap.com**

Our smartphones are notorious for collecting bacteria, with some reports suggesting they can be around seven-times dirtier than a toilet. Rather than cleaning your phone with a disposable wipe, the PhoneSoap Pro uses ultraviolet (UV) light to sterilise your phone and claims to kill 99.99 per cent of the bacteria in only five minutes. This compact sterilisation case can accommodate a wide range of smartphones and small electronics such as wireless earbuds.

© simplehuman

## TUSHY Classic

Price: **$109 (approx. £88)**
**www.hellotushy.com**

Toilet roll has become a hot commodity in recent times, so to stay hygienic in the bathroom, attachable bidets such as the TUSHY might be the way forward. With a quick ten-minute installation, this toilet accessory simply sits beneath your toilet seat and connects to your water source without the need for electricity or a pump. With adjustable pressure and nozzle direction, the TUSHY can accommodate the whole family.

© TUSHY

## 266ml rechargeable sensor pump

Price: **£69.95 / $60**
**www.simplehuman.com**

The importance of washing our hands has probably never been more prevalent than now during this global pandemic. However, while bunkering down in the house with your family, each gunning for the hand soap, keeping the soap dispenser clean and relatively free from bacteria can be a challenge. With the rechargeable sensor pump by simplehuman, simply place your hand beneath the nozzle and the built-in sensor will trigger, dispensing a serving of liquid soap. With three months of use on a single charge, this compact bathroom accessory is a great way to stay safe and clean while at home.

© robot

## pureAir FRIDGE

Price: **$49 (approx. £40)**

**www.greentechenv.com**

Using ionisation technology, the pureAir FRIDGE claims to destroy bacteria and neutralise pesticides autonomously. This small air purifier sits wirelessly between the fruit and vegetables in your fridge, maintaining fresh air within, reducing the ethylene gases produced by decaying food and also removing any unwanted odours. This compact device uses a lithium-ion rechargeable battery that can last 18 to 24 days on one charge. When power is running low the built-in photosensor technology triggers an audible alarm when the fridge door is opened.

## Braava jet m6

Price: **£699.99 / $499.99**

**www.irobot.com**

Expanding its home-cleaning robot range with the Braava jet m6, iRobot has created the latest in autonomous floor mopping devices. Automatically selecting the cleaning method, the Braava uses mapping pads that help break up grime or sweeping pads to capture dirt or hair. The Braava also comes equipped with a pressure jet spray to clean the floor. Using the companion app Braava can be summoned on command, or you can simply schedule a daily route to regularly freshen up your household.

© irobot

© Coway

## Coway Airmega 400S

Price: **$849 (approx. £686)**

**www.cowaymega.com**

In a time where we are all bundled up in our homes, you might be considering the quality of air inside. The Conway Airmega 400S boasts the ability to remove 99.97 per cent of particles, including pollen and pollutants, in the air using its combination active-carbon filters. App-controlled, this home air-purification system will monitor your home's air quality and make automatic adjustments to its fan speed to improve air quality in real-time.

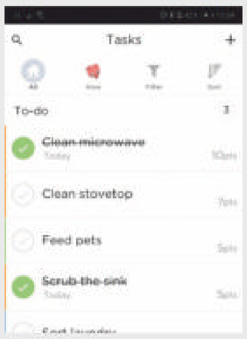
## APPS & TOOLS

### OurHome

Developer: **OurHome**

Price: **Free / Google Play / App Store**

Keep on top of daily chores with this organisational app. Allocate tasks to different members of the household and gain points when a task is done.

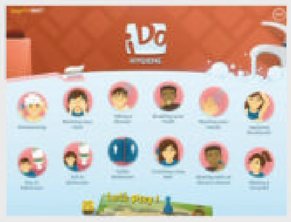


### iDo Hygiene

Developer: **C.E.T – THE CENTER FOR EDUCATIONAL TECHNOLOGY**

Price: **Free / App Store**

This app offers tutorials and games for personal hygiene and is designed for those on the autistic spectrum and with other special needs.

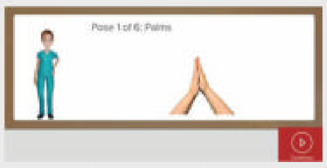


### SureWash

Developer: **SureWash**

Price: **Free / Google Play / App Store**

Learn the World Health Organization's hand-washing technique with this easy-to-use app. With the help of your smartphone camera, this app can judge your technique and give you feedback.

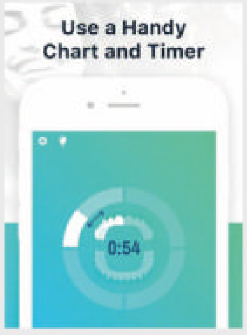


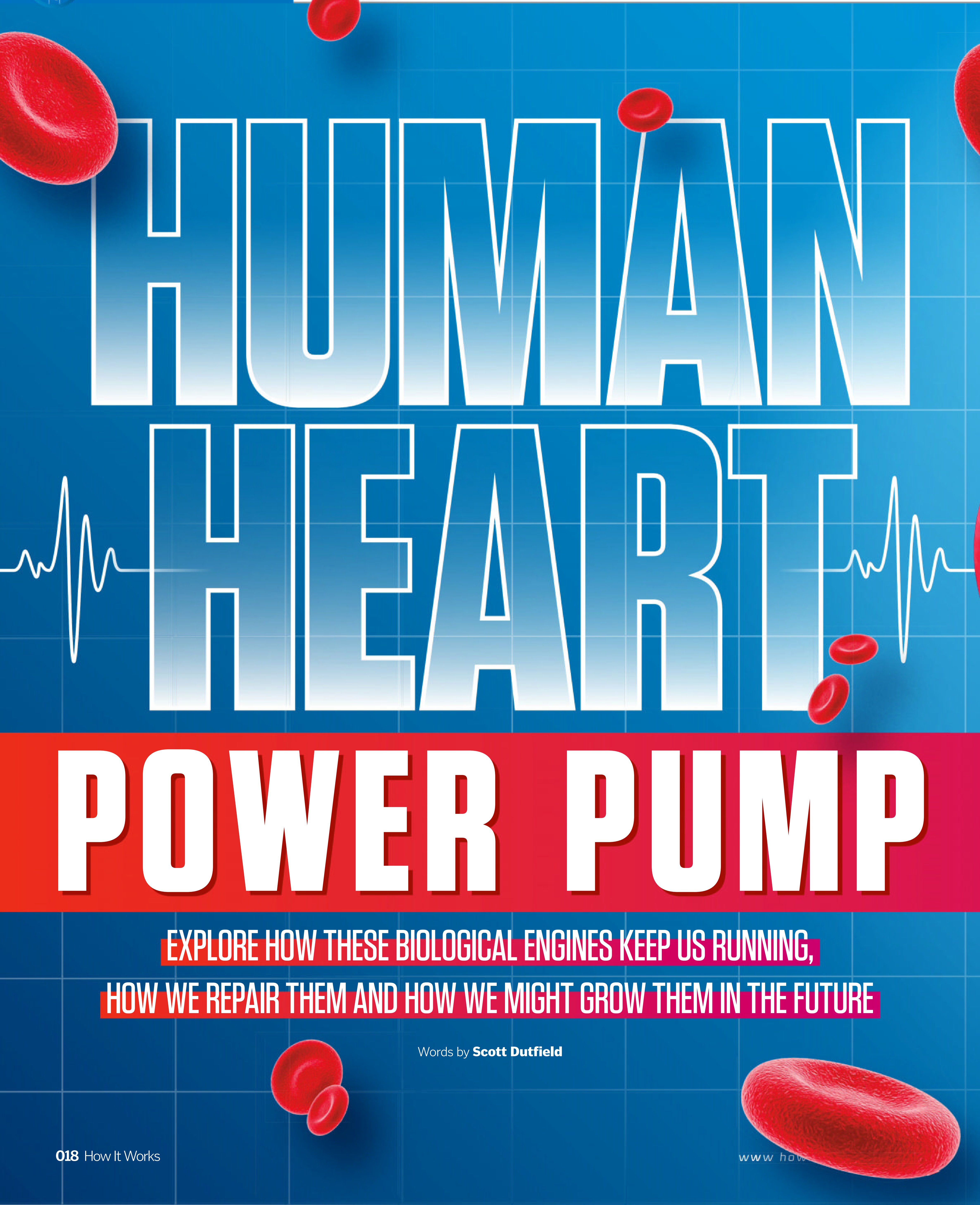
### Dental Hygiene

Developer: **OptiLife Apps**

Price: **Free / App Store**

Keep your oral hygiene in check. This dental app will let you know when and where to brush your teeth while offering dentist-recommended tips.





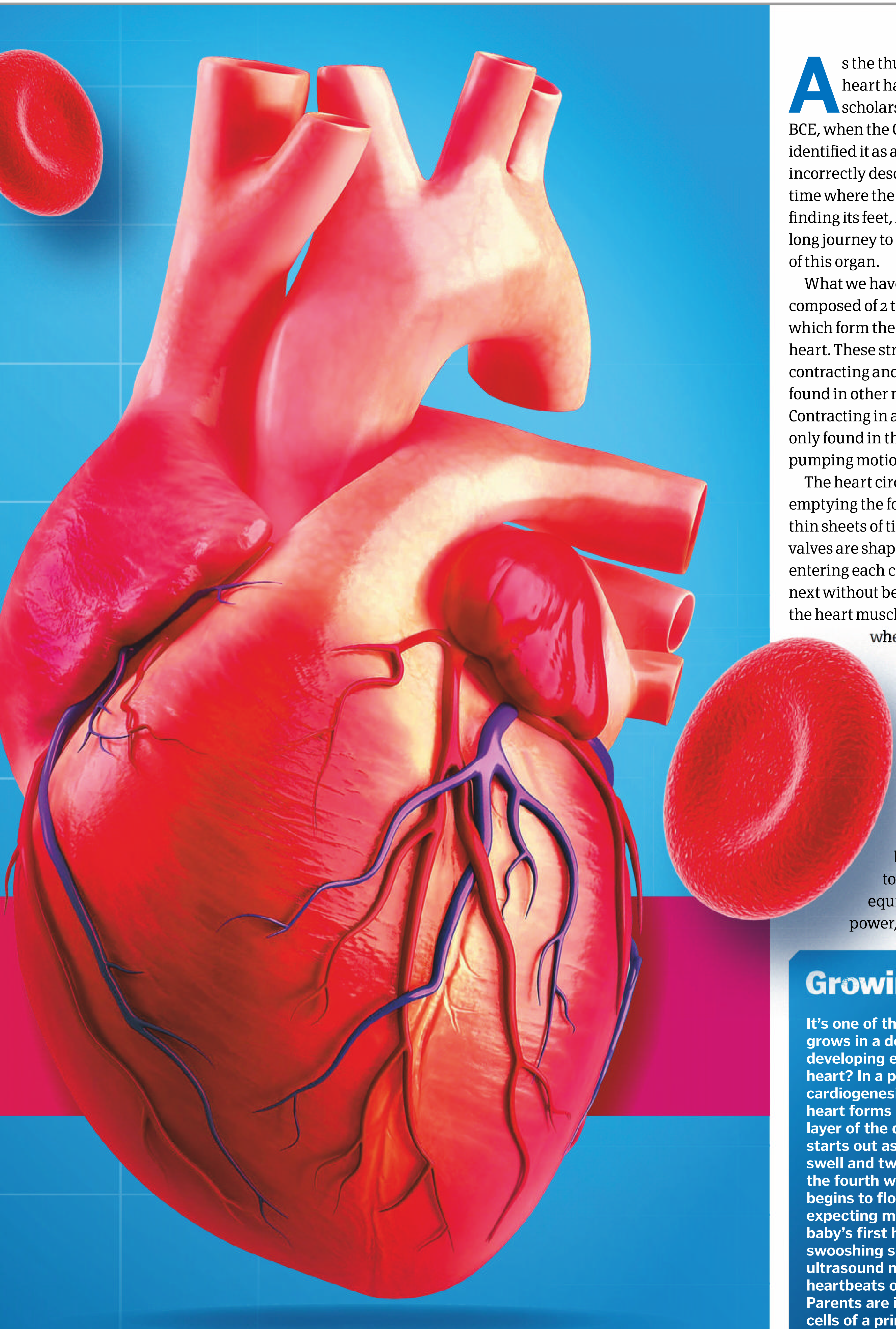
# HUMAN HEART

# POWER PUMP

EXPLORE HOW THESE BIOLOGICAL ENGINES KEEP US RUNNING, HOW WE REPAIR THEM AND HOW WE MIGHT GROW THEM IN THE FUTURE

Words by **Scott Dutfield**

**DID YOU KNOW?** *Around 610,000 people die from heart disease each year in the US*



As the thumping drum in our chests, the heart has piqued the scientific intrigue of scholars as far back as the fourth century BCE, when the Greek philosopher Aristotle identified it as an organ with chambers, albeit incorrectly describing it as having three. In a time where the science of the human body was finding its feet, Aristotle began the millennia-long journey to our modern-day understanding of this organ.

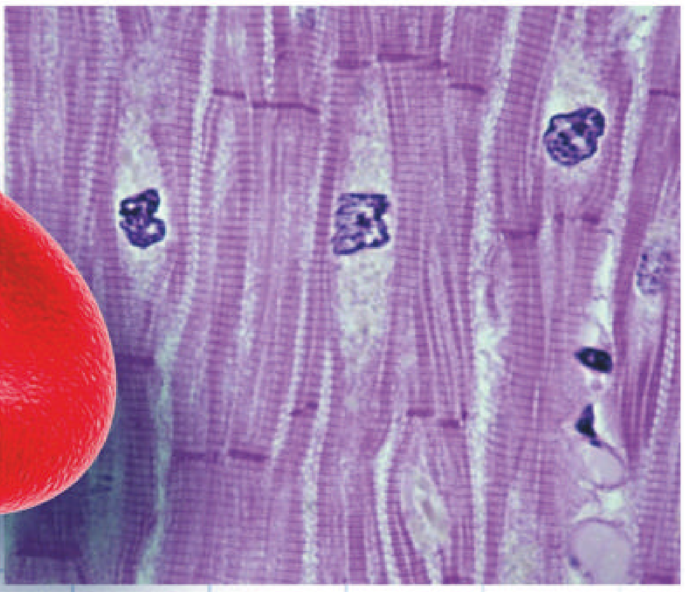
What we have come to learn is that the heart is composed of 2 to 3 billion cardiac muscle cells, which form the four chambers of a beating heart. These striated cells have a similar contracting and relaxing movement to cells found in other muscles around the body. Contracting in a wave motion, cardiac cells are only found in the heart and facilitate the natural pumping motion of the organ.

The heart circulates blood by filling and emptying the four chambers with the help of thin sheets of tissue acting as valves. These valves are shaped in such a way that the blood entering each chamber doesn't leak into the next without being opened by a contraction of the heart muscle. But how does your heart know when to pump? Luckily our hearts don't require us to consciously command beats, otherwise we would use our brains for nothing else to achieve the 35 million beats a year we need to survive. Instead our hearts operate under what is referred to as a myogenic response. Much like the way the brain receives electrical impulses to function, the heart is also equipped with its own impulse power, known as the sinus node. At the

## Growing a heart

**It's one of the first vital organs that grows in a developing foetus, but how do developing embryos create a functioning heart? In a process known as cardiogenesis, during pregnancy the heart forms from the mesoderm (middle) layer of the developing embryo. The heart starts out as a pair of tubes that fuse, swell and twist into the final form, and by the fourth week of pregnancy the blood begins to flow. At the sixth week, expecting mothers can listen to their baby's first heartbeats. However, the swooshing sounds that emanate from an ultrasound machine are not the heartbeats of a fully formed heart. Parents are instead hearing the fluttering cells of a primitive heart; it is not until 12 weeks of pregnancy that a foetal heart will resemble a fully-developed heart.**

upper-right chamber of the heart is a small mass of tissue that generates an electrical stimulus. This travels down the heart, causing the cardiac muscle to contract and in turn forcing blood from one chamber to the next. The upper chambers are the first to be stimulated by the sinus node, filtering down to the lower chambers. As the electrical stimulus travels from the sinus node it reaches another node called the atrioventricular node (AV) where it begins to slow down. Passing the AV, the stimulus travels down a pathway called the bundle of His, where it splits off to each ventricle. This electrical journey allows the upper atrium chambers of the heart to contract a fraction of second faster than the ventricles, allowing blood to fill the ventricles before the next contraction pumps it back out.



© Getty

The heart is comprised of striated cardiac muscle cells

## Making blood blueprints

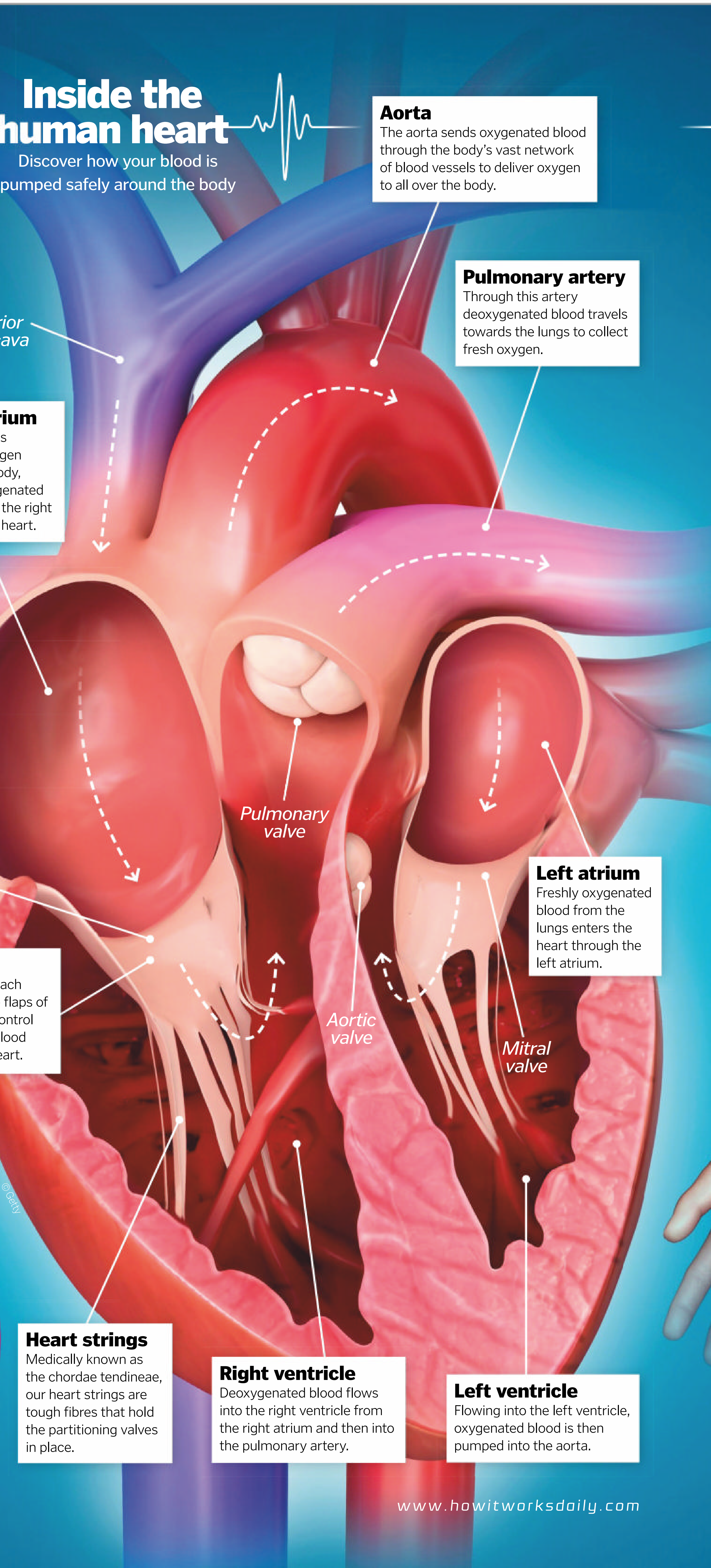
**In 1649 English physician William Harvey described accurately how the heart pumps blood around the body. After studying medicine at the University of Padua, Italy, in 1602 Harvey returned to England as a practising physician. Just 16 years later he established himself as a doctor to the royals, James I and his son Charles I. Arguably his greatest achievement, however, was his work on the body's circulatory system. In 1628 Harvey published his work on the anatomy of animals' hearts in a book entitled *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus* (An Anatomical Study of the Motion of the Heart and of the Blood in Animals). In this study he presented evidence collected from some 40 animal species, including some human dissections.**

William Harvey pioneered our understanding of the human heart and mapped the circulatory system

Source: Wiki/XXXX

# Inside the human heart

Discover how your blood is pumped safely around the body



© Getty

**Aorta**
The aorta sends oxygenated blood through the body's vast network of blood vessels to deliver oxygen to all over the body.

**Pulmonary artery**
Through this artery deoxygenated blood travels towards the lungs to collect fresh oxygen.

**Right atrium**
Blood that has delivered oxygen around the body, called deoxygenated blood, enters the right atrium of the heart.

**Left atrium**
Freshly oxygenated blood from the lungs enters the heart through the left atrium.

**Valves**
Separating each chamber are flaps of tissue that control the flow of blood within the heart.

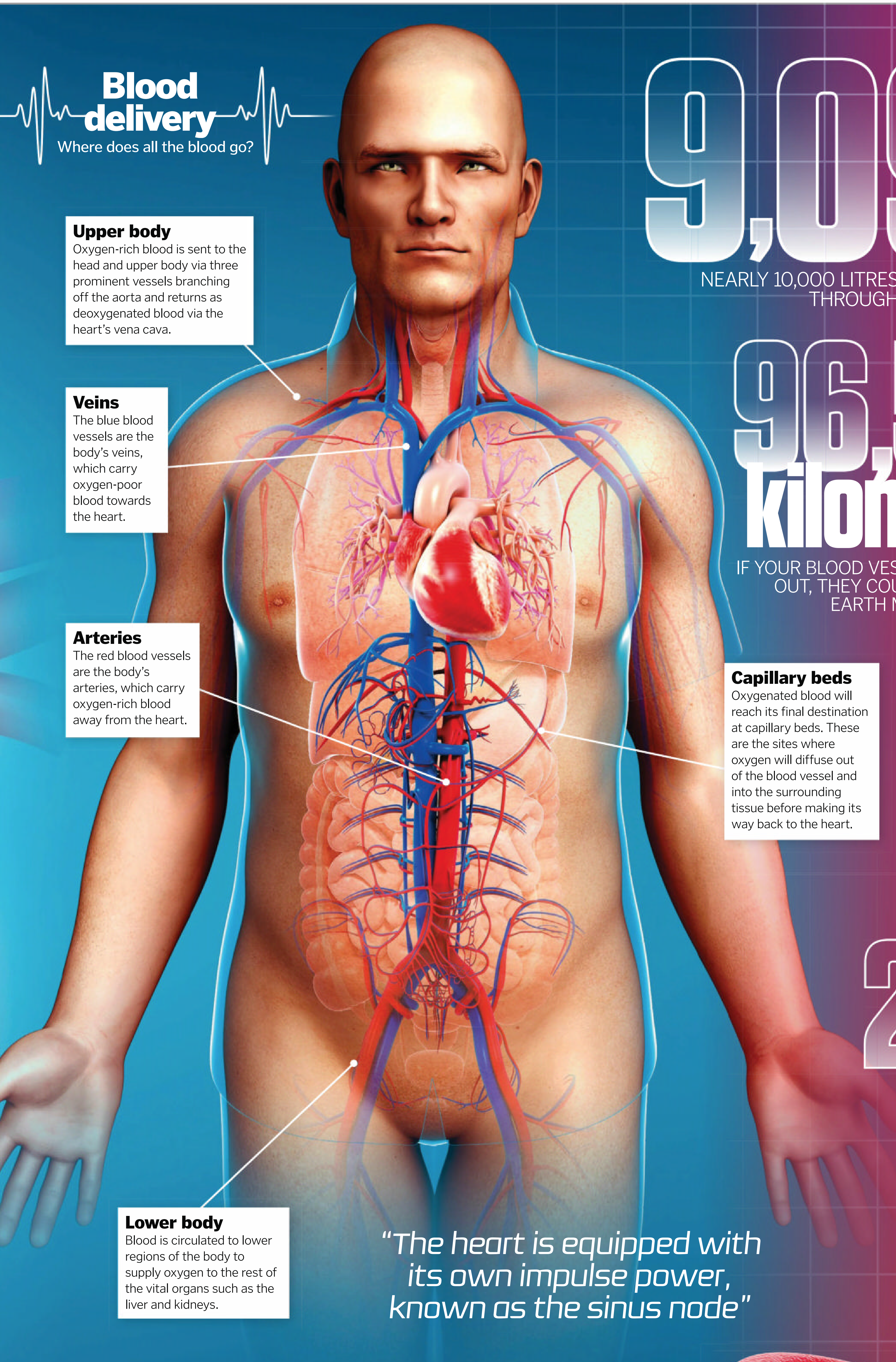
**Heart strings**
Medically known as the chordae tendineae, our heart strings are tough fibres that hold the partitioning valves in place.

**Right ventricle**
Deoxygenated blood flows into the right ventricle from the right atrium and then into the pulmonary artery.

**Left ventricle**
Flowing into the left ventricle, oxygenated blood is then pumped into the aorta.

# Blood delivery

Where does all the blood go?



**Upper body**
Oxygen-rich blood is sent to the head and upper body via three prominent vessels branching off the aorta and returns as deoxygenated blood via the heart's vena cava.

**Veins**
The blue blood vessels are the body's veins, which carry oxygen-poor blood towards the heart.

**Arteries**
The red blood vessels are the body's arteries, which carry oxygen-rich blood away from the heart.

**Capillary beds**
Oxygenated blood will reach its final destination at capillary beds. These are the sites where oxygen will diffuse out of the blood vessel and into the surrounding tissue before making its way back to the heart.

**Lower body**
Blood is circulated to lower regions of the body to supply oxygen to the rest of the vital organs such as the liver and kidneys.

## 9,090

NEARLY 10,000 LITRES OF BLOOD IS PUMPED THROUGH YOUR HEART PER DAY

## 96,560 kilometres

IF YOUR BLOOD VESSELS WERE STRETCHED OUT, THEY COULD WRAP AROUND THE EARTH MORE THAN TWO TIMES

## 100,000

THE NUMBER OF HEARTBEATS PER DAY FOR A NORMAL HEART

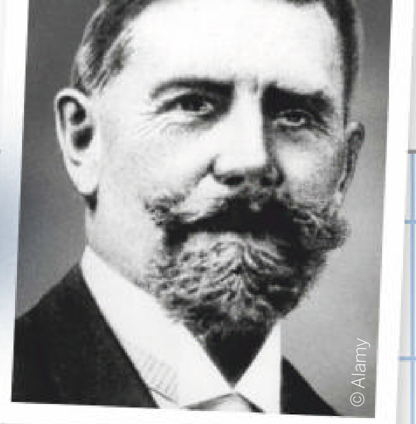
## 200-425 GRAMS

ADULT HEARTS CAN WEIGH AS MUCH AS A CAN OF SOUP

> *"The heart is equipped with its own impulse power, known as the sinus node"*

# FIXING A BROKEN HEART

## HOW MEDICINE HAS ADVANCED ACROSS DECADES TO KEEP OUR HEARTS BEATING

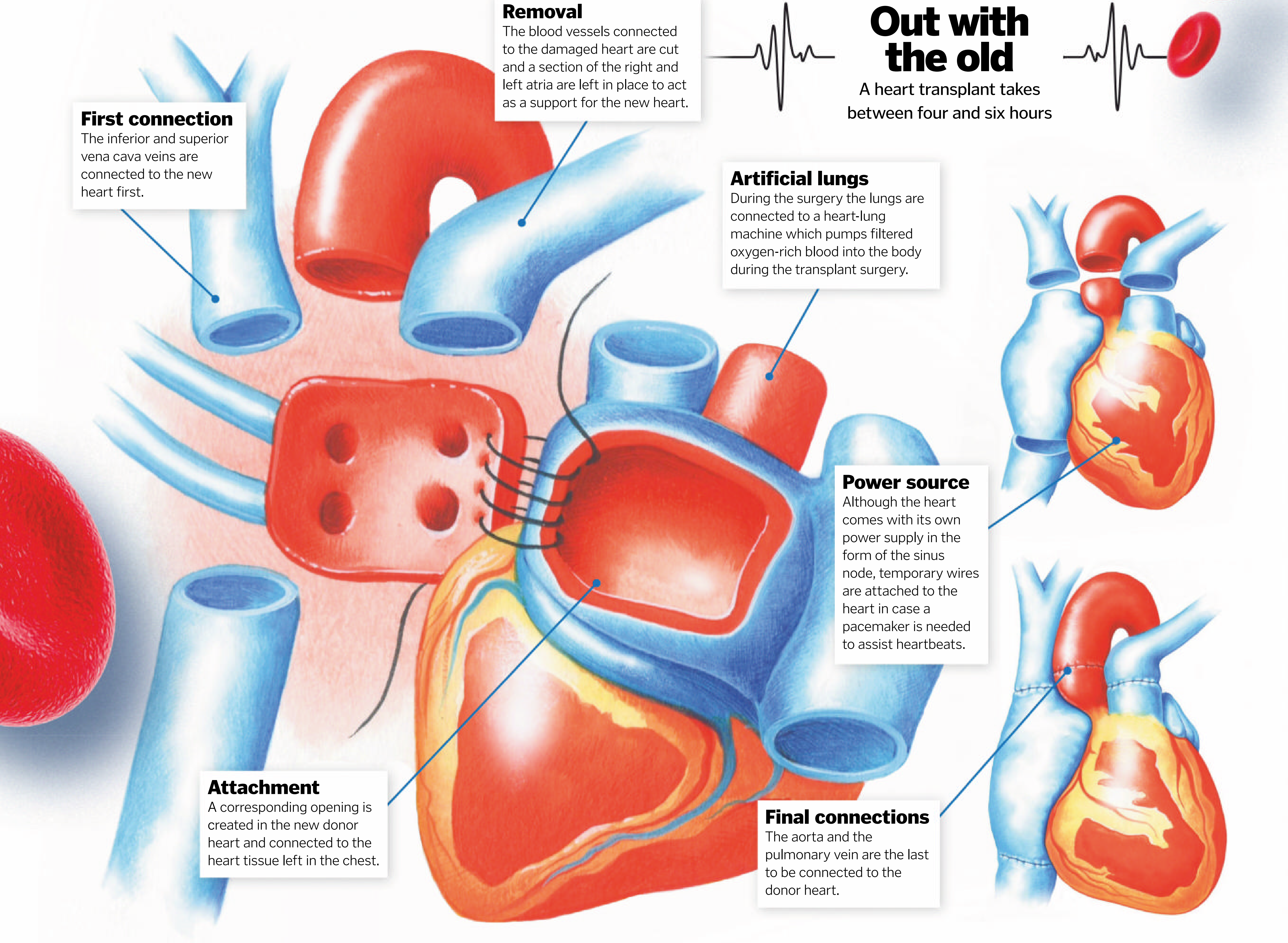

© Alamy

Dr Ludwig Rehn was the first to perform any kind of successful surgery on a beating heart

People often say that it takes time to heal a broken heart, and when it comes to cardiac medicine, they aren't wrong. Before 1896 scholars and scientists had a good idea of the form and function of the human heart. However, the ability to surgically repair a damaged organ was still unheard of. That was until German surgeon Dr Ludwig Rehn stepped in to fix the heart of a dying patient who had suffered a stab wound to their right ventricle.

Having opened the patient's chest with a 14-centimetre incision, Rehn witnessed the flowing blood within. Working quickly to locate the source of the bleeding, Rehn discovered a tear in the sunken heart's pericardium – the double-walled sac encapsulating the heart. Swiftly diving into the open chest with a surgical needle and thread, Rehn began suturing the wound in an attempt to stem the bleeding. Three sutures were sown to close the wound and completely stopped blood from escaping. The surgery was a success and the patient survived.

Sewing that final suture not only saved a man's life, but at that moment cardiac surgery was born. Since Rehn's pioneering – albeit unplanned – advancement in medicine, many more have followed in his footsteps to create a crucial branch of surgery that has saved countless lives. From the first operation on a heart valve in 1925 to the first angioplasty in 1977, cardiac surgeries and procedures have continued to develop and diversify. However, one of the most triumphant milestones in cardiac medicine was successfully transplanting a human heart into the chest of another. It was a feat in medicine that not many would have



## Out with the old

A heart transplant takes between four and six hours

**Removal**
The blood vessels connected to the damaged heart are cut and a section of the right and left atria are left in place to act as a support for the new heart.

**First connection**
The inferior and superior vena cava veins are connected to the new heart first.

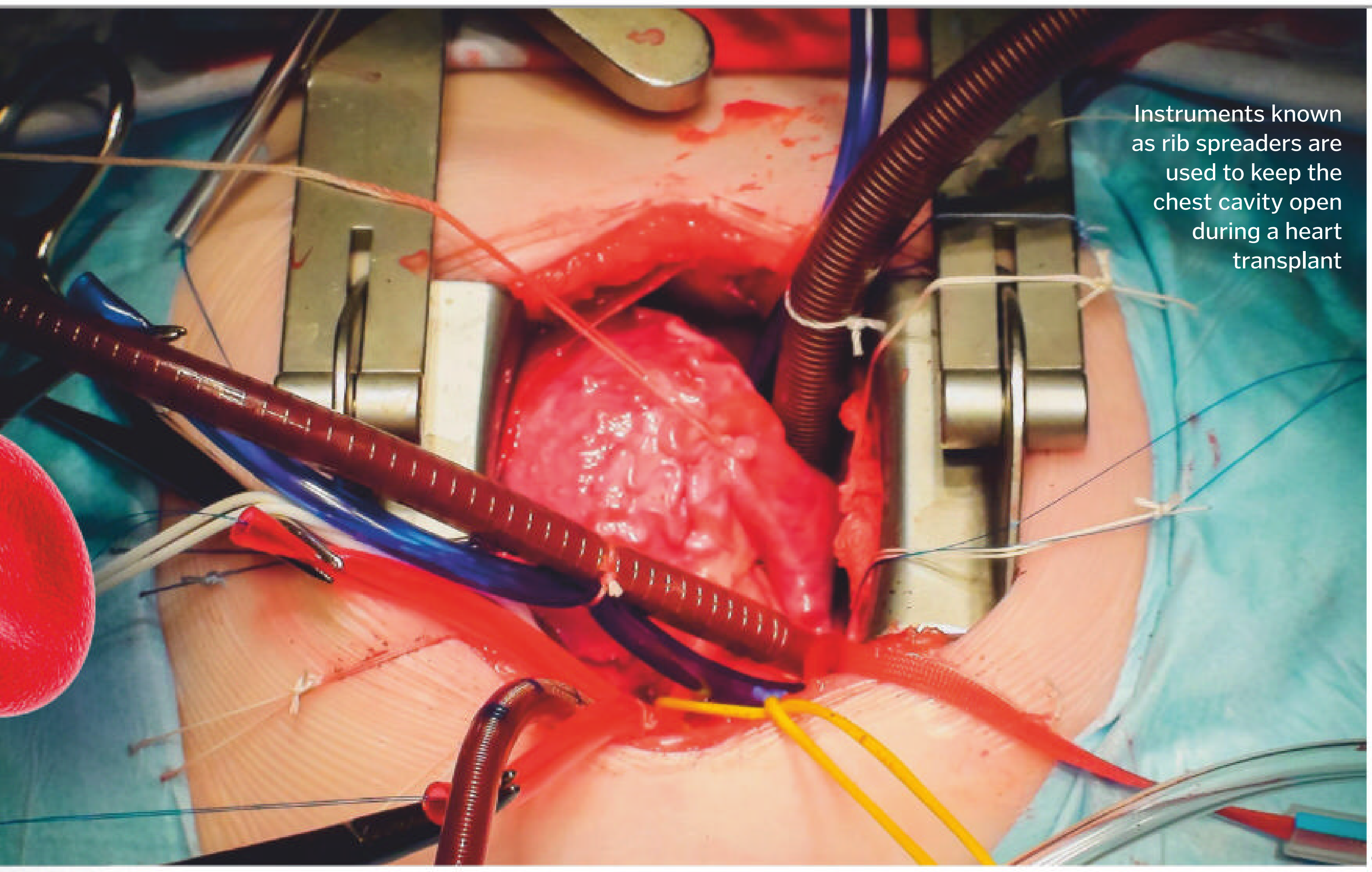
**Artificial lungs**
During the surgery the lungs are connected to a heart-lung machine which pumps filtered oxygen-rich blood into the body during the transplant surgery.

**Power source**
Although the heart comes with its own power supply in the form of the sinus node, temporary wires are attached to the heart in case a pacemaker is needed to assist heartbeats.

**Attachment**
A corresponding opening is created in the new donor heart and connected to the heart tissue left in the chest.

**Final connections**
The aorta and the pulmonary vein are the last to be connected to the donor heart.

**DID YOU KNOW?** *The blue whale has the largest heart, weighing in at around 199.5 kilograms*

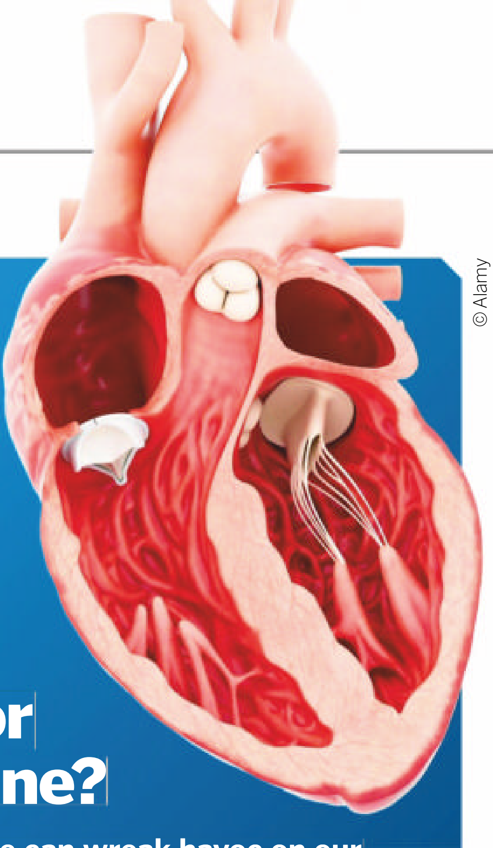

Instruments known as rib spreaders are used to keep the chest cavity open during a heart transplant

© Alamy

thought possible at the time of Rehn's revolutionary new surgery, but South African surgeon Christiaan Barnard achieved the impossible when he completed the world's first successful human heart transplant in 1967.

In some cases of severe heart disease, doctors are left with no choice but to seek out a new heart for their patient. Donor hearts are taken from the chests of those who have been declared 'brain dead', whereby neurological functions are absent but life-support machines are keeping their body and other vital organs viable for donation. How a new heart is transplanted can be thought of like installing a hard drive into a computer. The objective is making sure all of the wires, or in the heart's case, blood vessels, are connected correctly. But unlike a computer, the human body doesn't like it when you install something new. Our immune system attacks any invading tissue it deems foreign to the body, so a new heart is a prime target.

One of the biggest challenges of a transplant is managing the body's rejection of the new organ. To combat this self-sabotage, transplant patients will take lifelong anti-rejection medicine to reduce the immune response to the heart.


Small mechanical valves are surgically implanted to replace those typically damaged by heart disease

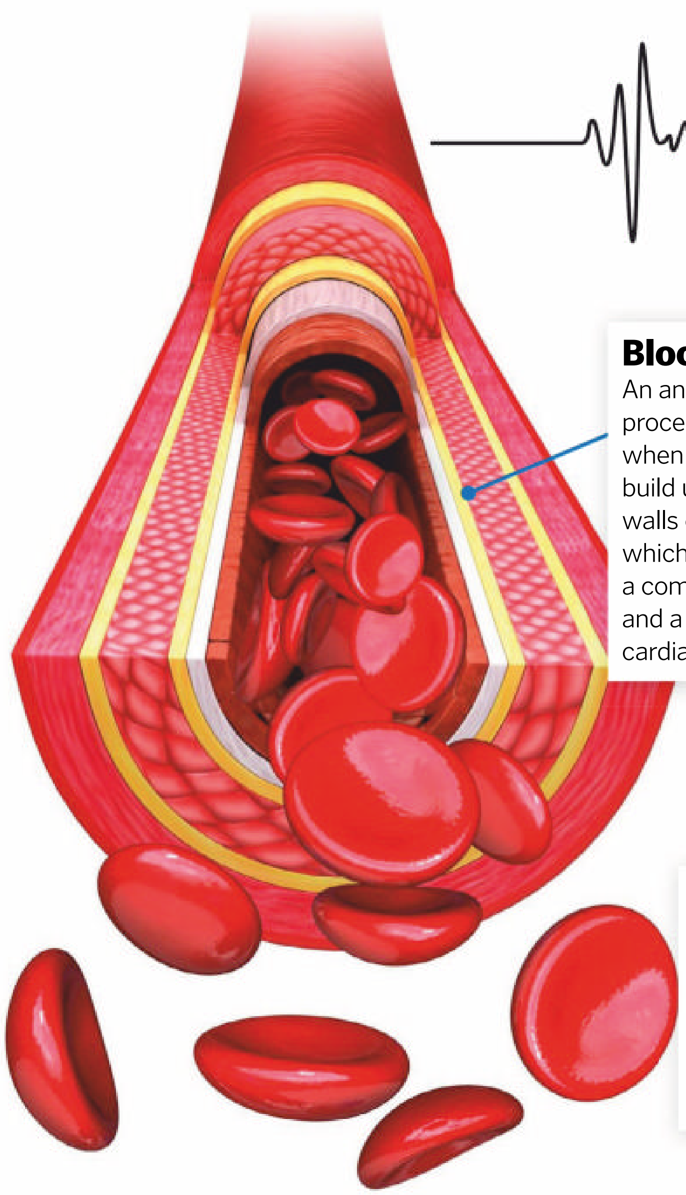
© Alamy

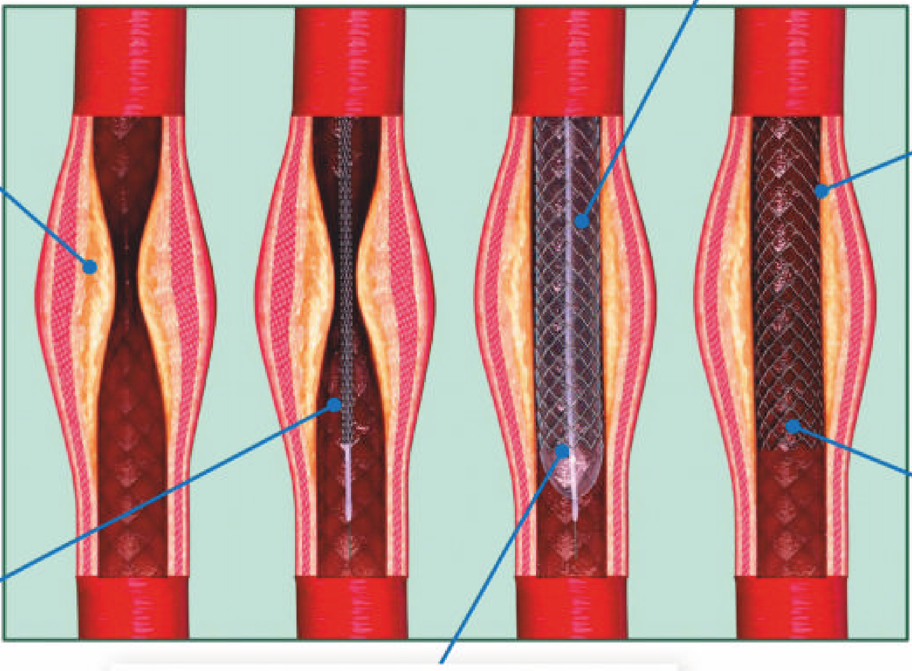
## Beef, pork or machine?

**Heart disease can wreak havoc on our internal blood pumps in many different ways. But in cases where only the heart's valves are affected, science has created three replacement valves that can save lives. Tissue collected from animal donors such as cows and pigs known as bioprosthetic valves have been used to swap out damaged valves. These can last for around 10 to 20 years. In some rare cases human donor valves have also been used as replacements. However, ditching the damaged valve for a mechanical valve has become common practice due to their longevity. Often made from carbon and metal, these engineered flaps are said to offer the longest lifespan, with around 20 to 30 years without further surgery. This does, however, mean that the patient must remain on blood-thinning medication to prevent any blood clots from forming. Should a clot develop, they can wedge themselves in the valve's hinges or flaps, causing a malfunction.**

## Opening the blood highway

How do surgeons stop blood cell traffic from reaching a standstill?





**Blockage**
An angioplasty procedure is needed when fatty deposits build up along the walls of blood vessels, which runs the risk of a complete blockage and a potential cardiac arrest.

**Infiltration**
A wire mesh coil, called a stent, is inserted around a deflated balloon between the fat build-up.

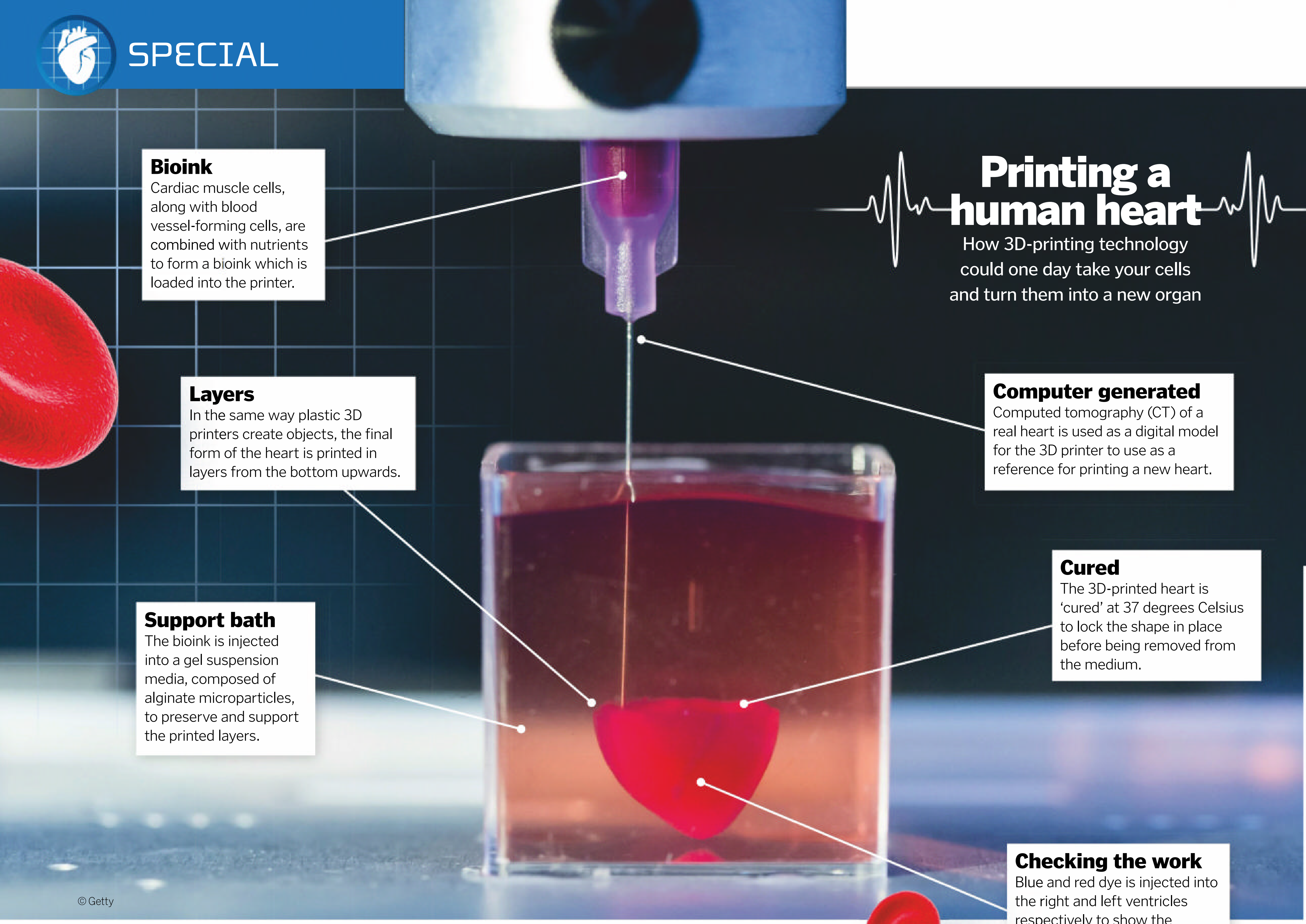
**Inflation**
The balloon is then inflated, expanding the mesh stent, opening the space within the blood vessel and allowing blood to freely move through.

**Locked in**
When the stent is expanded it locks into place within the vessel where it will remain indefinitely to support the blood vessel.

**Medicated**
Some stents are coated in medication to help prevent further fat build-up.

**Removal**
Once the stent is locked in place, the balloon is deflated and removed from the vessel.

© Getty



## Printing a human heart

How 3D-printing technology could one day take your cells and turn them into a new organ

**Bioink**
Cardiac muscle cells, along with blood vessel-forming cells, are combined with nutrients to form a bioink which is loaded into the printer.

**Layers**
In the same way plastic 3D printers create objects, the final form of the heart is printed in layers from the bottom upwards.

**Support bath**
The bioink is injected into a gel suspension media, composed of alginate microparticles, to preserve and support the printed layers.

**Computer generated**
Computed tomography (CT) of a real heart is used as a digital model for the 3D printer to use as a reference for printing a new heart.

**Cured**
The 3D-printed heart is 'cured' at 37 degrees Celsius to lock the shape in place before being removed from the medium.

**Checking the work**
Blue and red dye is injected into the right and left ventricles respectively to show the chambers of the heart and the dividing wall, the septum.

© Getty

# FUTURE HEARTBEATS

## IN A WORLD GOVERNED BY EVOLVING TECHNOLOGY, WHAT COULD THE FUTURE HOLD FOR THE HUMAN HEART?

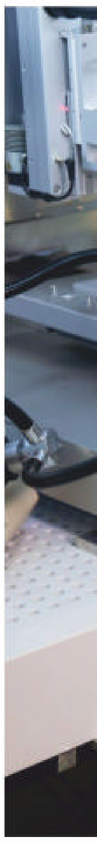
© Carmat

Technological advances could produce artificial hearts for transplants

Unlike our smartphones, the human heart isn't a piece of technology that can be upgraded each year for a newer, more efficient model. However, in recent decades medical research has explored the different roles technology can play in assisting, replicating and even creating a new beating heart as an alternative to human-to-human transplants.

First executed as a concept back in 1982 by Dr Barney Clark, an artificial heart typically mimics the ventricle function of a biological heart using various external power sources or pumps to circulate blood. This human-made organ has been used to treat heart disease patients over the years. However, so far it has only been implanted as a temporary fix for those awaiting a biological heart transplant. Developments in technology to create a long-lasting heart have seen varying degrees of success throughout the years, with mechanical breakdowns, infections and blood clots posing some of the largest hurdles. Hoping to answer the call for a long-term fix to heart disease is a biotech organisation, Carmat. With the use of two built-in miniature pumps, Carmat's artificial heart seeks to replicate the natural rhythm of a heartbeat using an external battery and control system that can monitor its functionality. It has an automatic response to the patient's physiological needs. Weighing only three kilograms, the Carmat heart has been successfully implanted into 5,000 patients so far during its trials.

The future of heart transplants could see a mechanical makeover with artificial hearts such as Carmat's creation. Could cardiac implants be lab-grown, or better still, printed? 3D printing has revolutionised not only the manufacturing industry, but has also opened the door to the potential of printing implantable biological organs. Up until April of last year, the branch of science exploring this possibility had managed to print tissue samples from different parts of the body. Now, a research team from Tel Aviv University, Israel, are the first to print a fully



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formed heart, equipped with functional blood vessels. The researchers used blood cells taken from human donors re-engineered into stem cells, then again transformed into the cardiac muscle cells that make up the heart. A collection of the cells form the ink for the printer to ultimately print a beating replicate. The science isn't quite there yet, though. The team only created a rodent heart-sized sample, but it showed a promising start in a journey that could see human-to-human heart transplants becoming obsolete. One of the many future challenges for the team is to explore a method that provides human-sized samples, and also a way to make the printed heart beat in the same way our hearts do.

A rodent-sized heart has been successfully created through 3D printing

© Getty

3D-printing technology could see artificial hearts being 'grown'

# Q&A How to print a 3D heart

© Carnegie Mellon University College of Engineering

Adam Feinberg is a professor of biomedical engineering and materials science and engineering at Carnegie Mellon University, Pennsylvania. With a team of researchers he has been using 3D printing to create functional components of the heart out of collagen – a protein found in your skin and muscles – with the future goal of building a fully functional heart. We caught up with him to talk about when we might see the first artificial heart implanted.

### What are the biggest challenges in 3D printing a working heart?

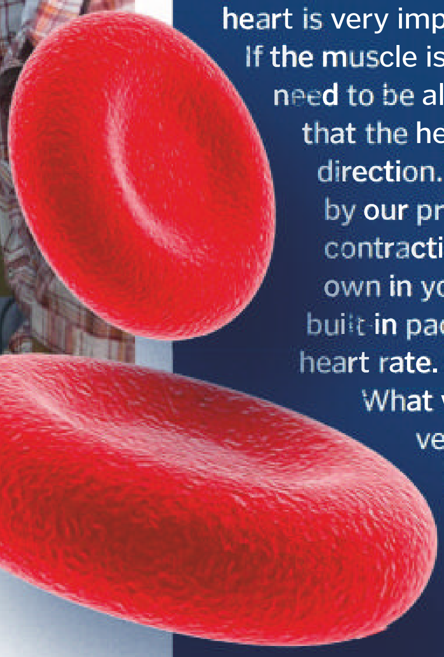
The problem with the cells in the human heart is that they cannot regenerate. That's one reason heart disease is such a problem. The only way that we can get new human heart muscle cells is using either an embryonic stem cell or an induced pluripotent stem (IPS).

IPS is advantageous because we don't need the embryonic stem cell; we can take a skin cell or any other cell of the body from an adult and then reprogram it into a stem cell that we can then make into cardiac [muscle cells]. The challenge there is generating the hundreds of billions of cells to make a heart. That's probably going to take people in my lab six months and a couple hundred thousand dollars to make enough cells for just one heart. We don't have the money or manpower to do that.

> "The cells in the human heart cannot regenerate"

### Printing the physical form of a heart is one thing, but how do you 3D print the ability to beat?

The heart muscle cells we use are already programmed when growing next to each other, and if they're at a high enough density they will interconnect and form continuous interconnected tissue. The structure of the heart is very important to the way it functions. If the muscle is contracting, all those cells need to be aligned in the proper direction so that the heart is contracting in the right direction. We were able to recreate that by our printing approach. To control the contraction, these cells beat on their own in your own heart because of the built in pacemaker that controls your heart rate. We don't have that right now. What we do have is an external mini version of a defibrillator [a device that shocks the heart with electricity] to stimulate all the cells to control the heart rate – and that's how we get synchronised functions. Ultimately, once we know how to build heart muscle we'll move on to the challenge of the [biological] pacemaker. But it's a little premature to work on the pacemaker because we have a good way of replicating that. That's something we might get to at one point, but the near-term challenge is just building the heart muscle.



### How far away are we from seeing a fully functional and implantable artificial heart in patients?

I think what you'll see initially is not replacing the whole heart, but replacing damaged parts of the heart in vivo in patients, whether it's a valve or part of the heart muscle wall. I could see initial human studies starting on that within ten years. I think the whole heart is more like 20 years. The problem with the heart is that if whatever you make fails, the patient is going to die. We will see 3D-printed tissues within people in the next 20 years, but I'm not super confident we're going to see it in the heart for that reason. There have been a lot of advances in stem cell science, and that's accelerating. There have been a lot of new computational tools. With some of the machine-learning and artificial-intelligence technologies that are being developed, I do see the potential for these timelines to be accelerated from a technology development standpoint. However, I think there are fundamental limitations for clinical trials that will just take the amount of time that they take. If we need to get through a five-year clinical trial, you know, before this is widely available for a patient population, then there's no way of getting around that because that's fundamental to the safety of the technology. Maybe we could see it sooner in about 15 years, but that would be quite optimistic.

© Carnegie Mellon University College of Engineering

Feinberg and his team have 3D printed a functional trileaflet heart valve out of collagen

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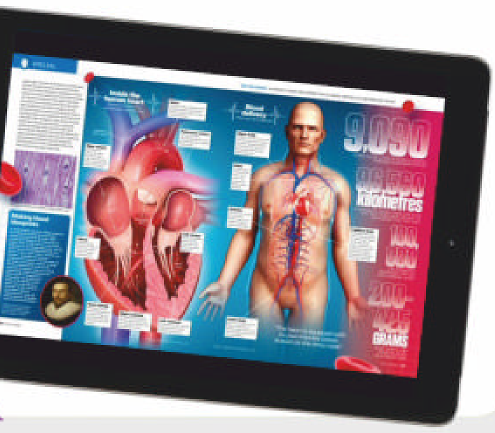

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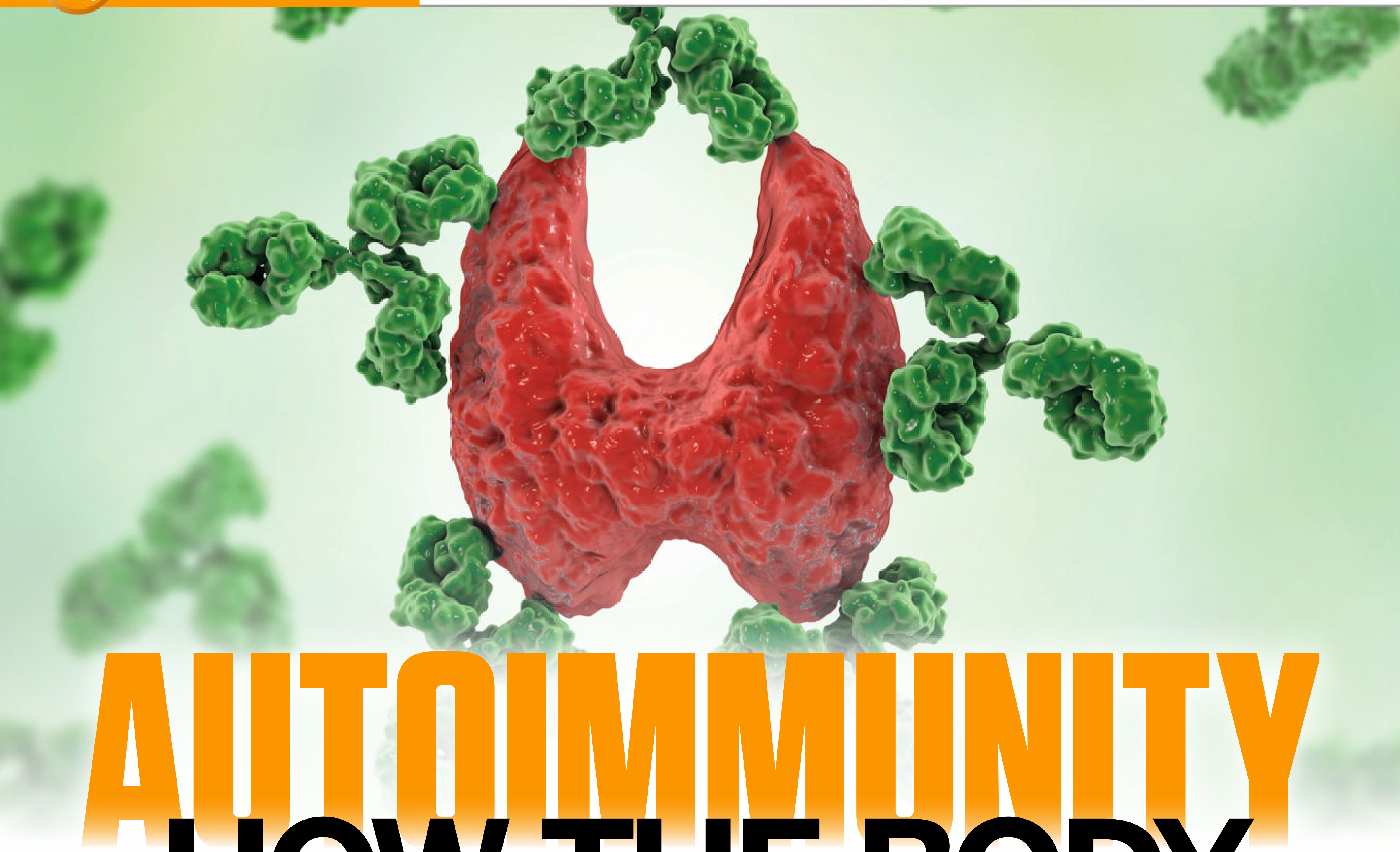


# AUTOIMMUNITY HOW THE BODY ATTACKS ITSELF

What happens when a system designed to protect you goes on the offensive?

Words by **Ailsa Harvey**

Your immune system saves your life every day, fighting off billions of pathogens before they are able to harm you. Without it the simple act of brushing your teeth could introduce a deadly volume of bacteria into your body. This being said, not everybody's immune system is entirely on their side. In some cases cells that are built to defend the body are falsely programmed to attack body tissue. This is referred to as autoimmunity and causes a range of symptoms and diseases.

Over 80 different autoimmune diseases have been discovered, but with many of them flagging up the same symptoms, diagnosis can be a lengthy process. A combination of tests is needed to rule out other possibilities and pinpoint which one someone is suffering from. While treatments are unable to cure these diseases, they help to make life for someone living with one much more tolerable by calming down the self-destructive response. This involves minimising the pain and inflammation that arises when the immune system goes on the attack. Maintaining a healthy lifestyle can also help to reduce symptoms and the impact these diseases have on an individual's life. This includes regular exercise and a well-balanced diet.

Although each of these diseases are caused by the same core actions of the immune system, there are a vast range of symptoms. Some conditions target a specific part of the body while others impact almost every area. Some autoimmune diseases are much more debilitating than others. One of the most common is Type 1 diabetes, with around 400,000 people suffering from it in the UK alone. In this case the immune system specifically targets insulin-producing cells in the pancreas. Insulin is essential as it helps us to use the sugar in food for energy and keeps blood sugar at a safe level. Type 1 diabetics need to inject insulin as their bodies are unable to produce it.

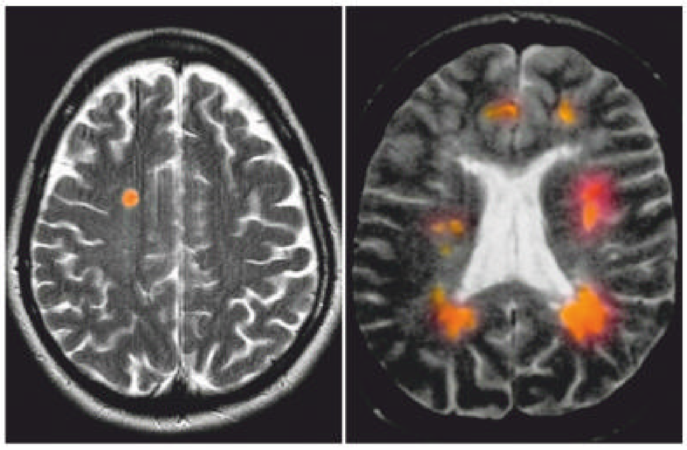
Rarer forms of autoimmune diseases are harder to diagnose. One example of this is Asherson's syndrome. This disorder causes a rapid development of blood clots all over the body. Several clots could form in a matter of hours in the most severe cases, with the risk of

© Getty

**DID YOU KNOW?** *One drop of your blood contains between 7,000 and 25,000 white blood cells*

organ failure throughout the body. Due to the range of areas impacted, the symptoms are broad and can coincide with other disorders. Since it was identified back in 1992, only 300 individuals have been diagnosed with this particular autoimmune disease and research is still ongoing as to why the attacked cells cause these clots in the first place.

Autoimmune diseases go against the core principle of the immune system, leaving people fighting their own bodies every day. They can emerge in anyone – regardless of age, gender or genetics – but tend to be more common in women, with some cases running in families. As millions of people worldwide are impacted by immune system malfunction and numbers continue to rise, there is still a lot to learn about these complex and diverse human diseases.

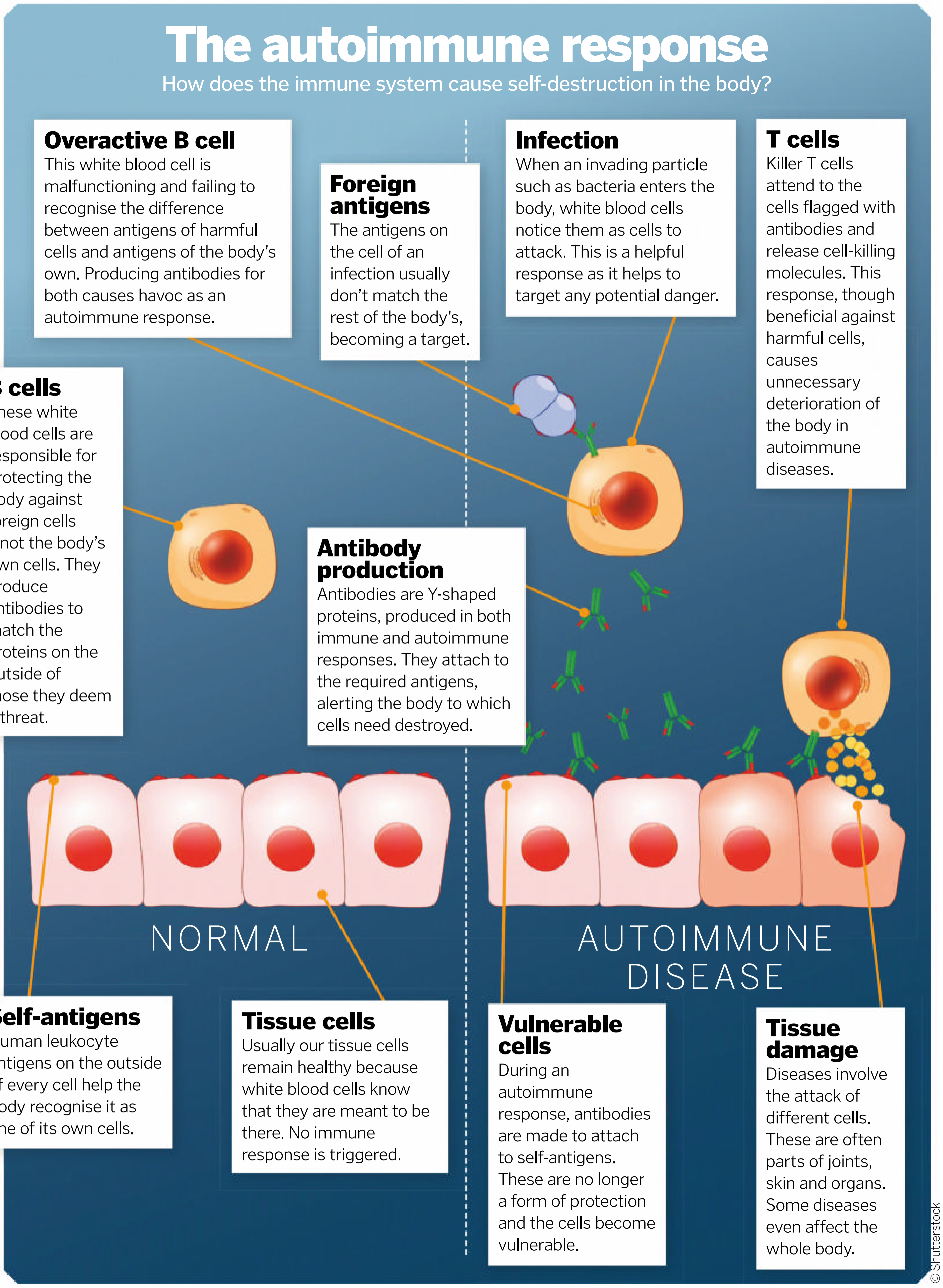


MRI scans can show the extent of brain shrinkage from multiple sclerosis

© Getty

## The autoimmune response

How does the immune system cause self-destruction in the body?



**Overactive B cell**
This white blood cell is malfunctioning and failing to recognise the difference between antigens of harmful cells and antigens of the body's own. Producing antibodies for both causes havoc as an autoimmune response.

**Foreign antigens**
The antigens on the cell of an infection usually don't match the rest of the body's, becoming a target.

**Infection**
When an invading particle such as bacteria enters the body, white blood cells notice them as cells to attack. This is a helpful response as it helps to target any potential danger.

**T cells**
Killer T cells attend to the cells flagged with antibodies and release cell-killing molecules. This response, though beneficial against harmful cells, causes unnecessary deterioration of the body in autoimmune diseases.

**B cells**
These white blood cells are responsible for protecting the body against foreign cells – not the body's own cells. They produce antibodies to match the proteins on the outside of those they deem a threat.

**Antibody production**
Antibodies are Y-shaped proteins, produced in both immune and autoimmune responses. They attach to the required antigens, alerting the body to which cells need destroyed.

**Self-antigens**
Human leukocyte antigens on the outside of every cell help the body recognise it as one of its own cells.

**Tissue cells**
Usually our tissue cells remain healthy because white blood cells know that they are meant to be there. No immune response is triggered.

**Vulnerable cells**
During an autoimmune response, antibodies are made to attach to self-antigens. These are no longer a form of protection and the cells become vulnerable.

**Tissue damage**
Diseases involve the attack of different cells. These are often parts of joints, skin and organs. Some diseases even affect the whole body.

© Shutterstock

## Spotting symptoms

Despite the number of diseases, many have these early symptoms in common

### FATIGUE

Fatigue is one of the most common symptoms across diseases. The central nervous system, a region impacted in most autoimmune variations, largely contributes to this exhaustion.

### JOINT PAIN

Several autoimmune diseases impact joints in the body, such as rheumatoid arthritis and lupus. Often when the immune system attacks itself joints become inflamed, creating pain and difficulty moving.

### SKIN PROBLEMS

As the human body's largest organ, it is a common target for attack in autoimmune diseases. The type of skin problem can highlight possible diseases. For example, butterfly-shaped rashes across the nose and cheeks are distinguishable as lupus.

### ABDOMINAL PAIN

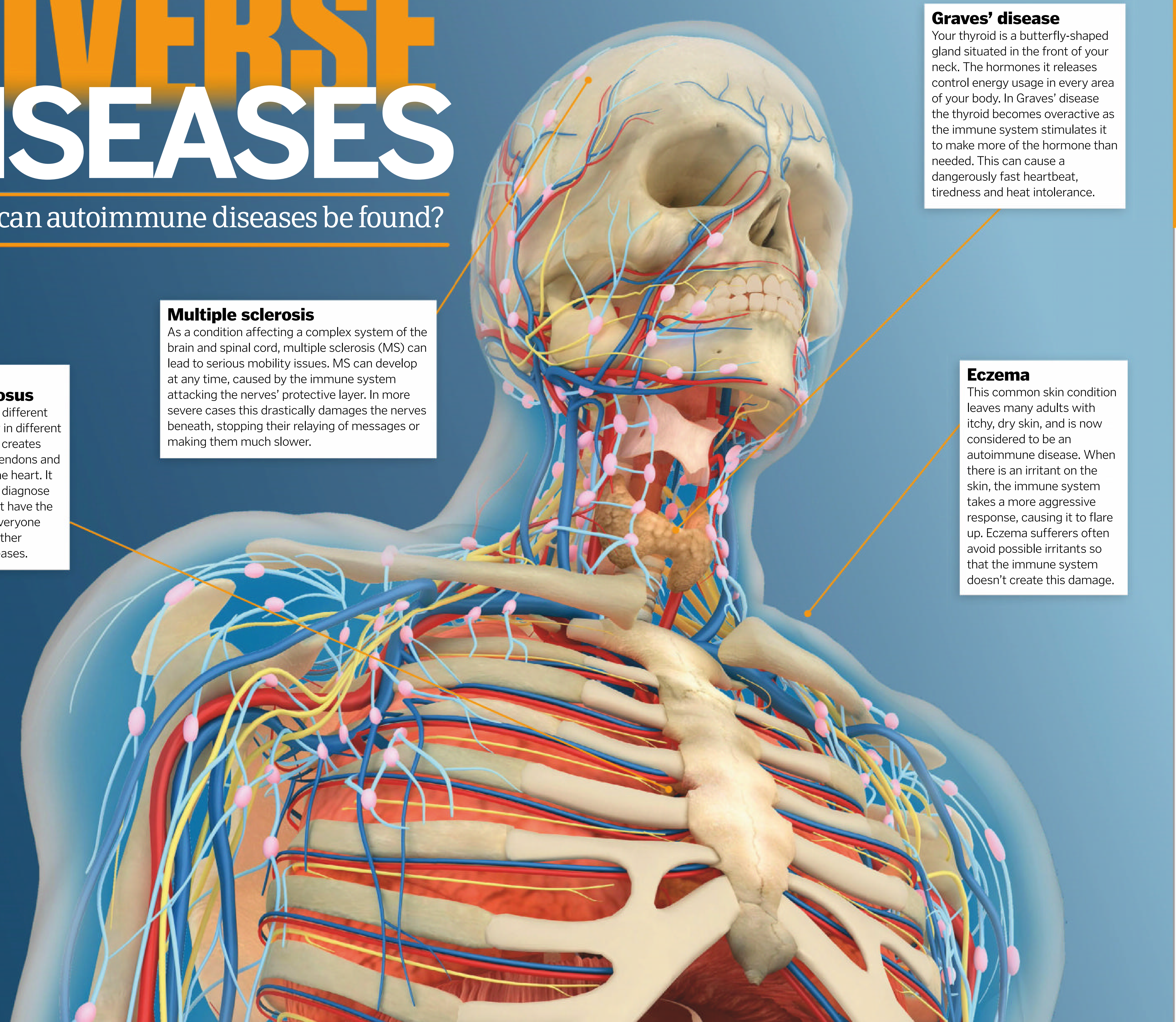
Both the stomach and abdominal muscles can become weakened or inflamed. This can often be brought on in the digestive system as an abnormal response to food.

### INFLAMMATION

Causing pain, redness, heat and swelling, inflammation is one of the initial signs of an autoimmune disease. This is your body's way of protecting injured tissue. For many of these diseases a major purpose of treatment is to prevent this inflammation.

# DIVERSE DISEASES

Where can autoimmune diseases be found?



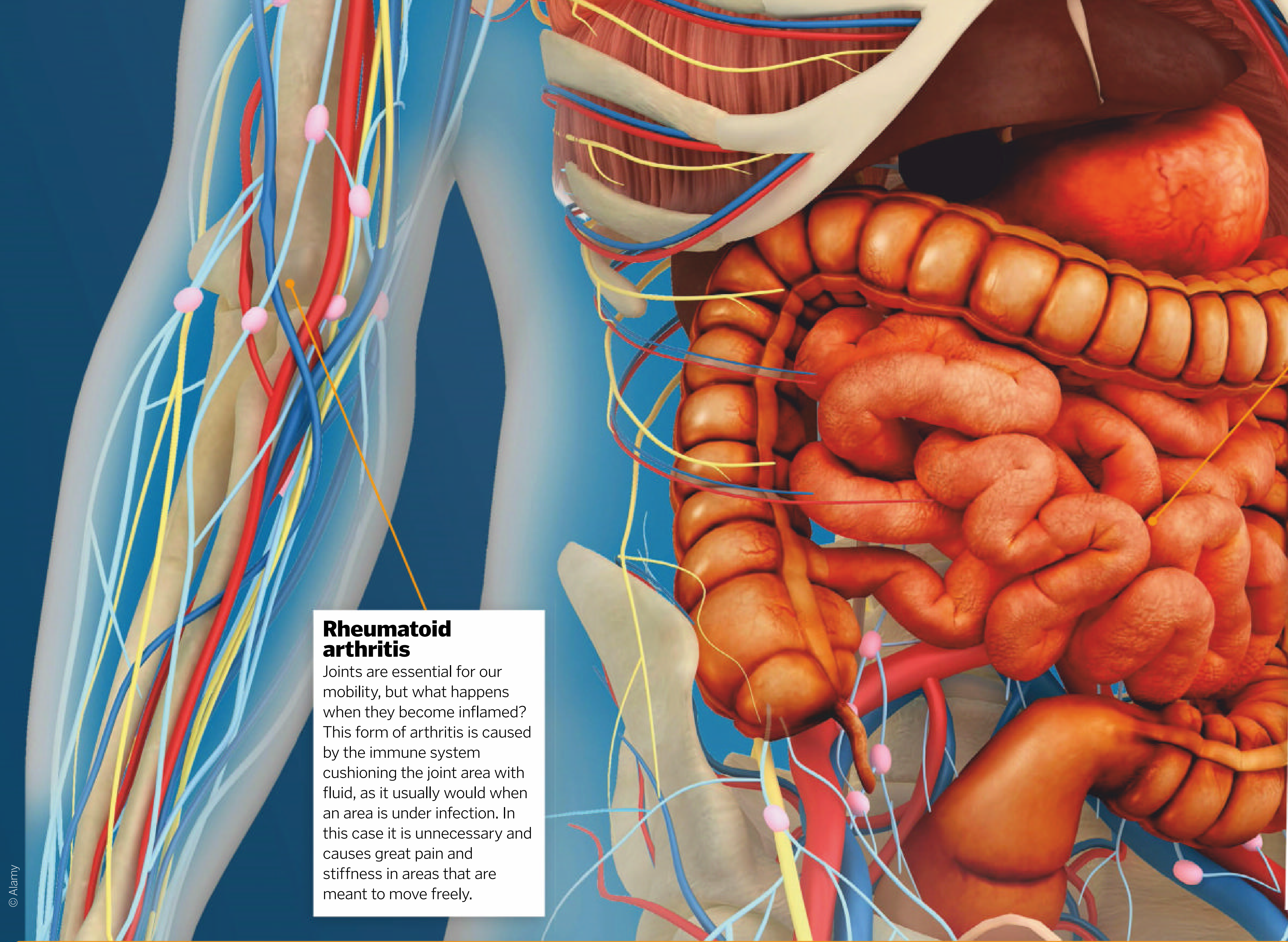
**Graves' disease**
Your thyroid is a butterfly-shaped gland situated in the front of your neck. The hormones it releases control energy usage in every area of your body. In Graves' disease the thyroid becomes overactive as the immune system stimulates it to make more of the hormone than needed. This can cause a dangerously fast heartbeat, tiredness and heat intolerance.

**Multiple sclerosis**
As a condition affecting a complex system of the brain and spinal cord, multiple sclerosis (MS) can lead to serious mobility issues. MS can develop at any time, caused by the immune system attacking the nerves' protective layer. In more severe cases this drastically damages the nerves beneath, stopping their relaying of messages or making them much slower.

**Lupus erythematosus**
Lupus can attack different areas of the body in different people, but often creates inflammation in tendons and organs such as the heart. It can take years to diagnose lupus as it doesn't have the same effect on everyone and can imitate other autoimmune diseases.

**Eczema**
This common skin condition leaves many adults with itchy, dry skin, and is now considered to be an autoimmune disease. When there is an irritant on the skin, the immune system takes a more aggressive response, causing it to flare up. Eczema sufferers often avoid possible irritants so that the immune system doesn't create this damage.

**DID YOU KNOW?** *An estimated 75 per cent of all autoimmune disease sufferers are women*



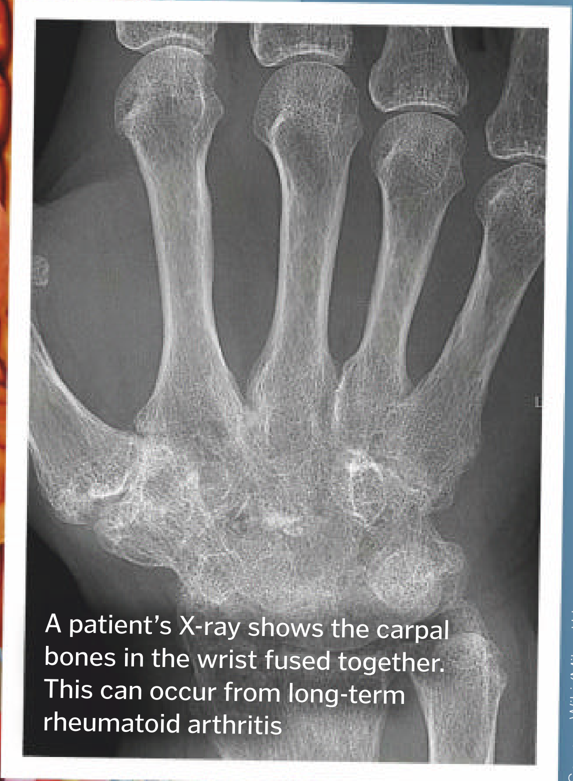
### Crohn's

Those with this disease can feel frequent abdominal discomfort at varying severity, diarrhoea, fatigue and weight loss. Causing issues within the digestive tract, most commonly at the end of the small intestine or the colon, Crohn's is an inflammatory bowel disease. When cells attack the inside of the intestines, they become extremely sore and inflamed.

### Rheumatoid arthritis

Joints are essential for our mobility, but what happens when they become inflamed? This form of arthritis is caused by the immune system cushioning the joint area with fluid, as it usually would when an area is under infection. In this case it is unnecessary and causes great pain and stiffness in areas that are meant to move freely.

© Alamy



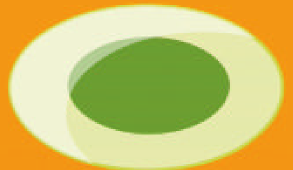
A patient's X-ray shows the carpal bones in the wrist fused together. This can occur from long-term rheumatoid arthritis

Source: Wiki/Mikael Häggström

## Testing for disease

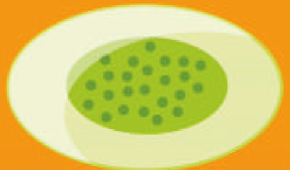
**If a doctor recognises symptoms of an autoimmune disease in their patient, they may ask them to take a blood test. This blood is then analysed using an antinuclear antibody (ANA) test. Antibodies are the proteins produced by the immune system to fight threats such as viruses and bacteria. Antinuclear antibodies, on the other hand, are antibody subtypes that target the nucleus instead: this is the core of your body's cells. If these are picked up in the blood sample, it could mean that the person has an autoimmune disorder.**

**ANA tests can help with diagnosis, with the antibody pattern within your cells' nuclei indicating what type of disease it could be. The antibodies are tagged with a fluorescent dye so that professionals can visually observe their pattern and abundance. Some people can show a positive ANA test even though they are healthy, so further testing is then required.**



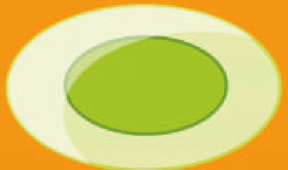
**Homogeneous**

This pattern appears as a total coverage of the nucleus. ANAs detected in these cases are targeting the chromatin which is found throughout the nucleus. This commonly indicates systemic lupus, mixed connective tissue disease or arthritis in children.



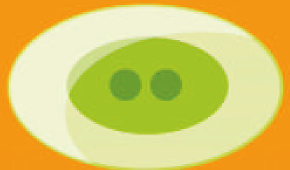
**Speckled**

A speckled pattern is also linked to lupus, as well as the skin conditions dermatomyositis and scleroderma. The antibody subtypes in these diseases are lightly distributed across the nucleus as they target specific nuclear proteins.



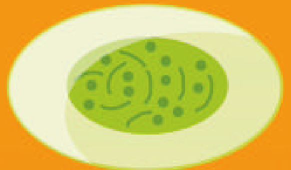
**Peripheral**

This result shows the luminescent antibodies' presence at the edge of the nucleus as they attach to proteins on the outer surface. This almost always diagnoses a patient with systemic lupus.



**Nucleolar**

Patterns displaying antibodies in clusters are a common test result for people suffering with polymyositis – a disease that inflames the upper arm and leg muscles. The nucleoli are the ANAs' focal point.



**Centromere**

The more complex centromere pattern varies based on the cell's stage. For cells which aren't dividing, the luminescence is scattered. When cells are about to divide, antibody presence congregates with the DNA molecules at the cells' centre and two opposite ends.

# How to make living machines

We're on the cusp of programmable life – what could this mean for our future?

Words by **Scott Dutfield**

The concept of a living machine might make you imagine a walking, talking humanoid. However, a research team from Tufts University, Massachusetts, has created microscopic machines that more closely resemble a tardigrade – a tiny living organism – than the Terminator.

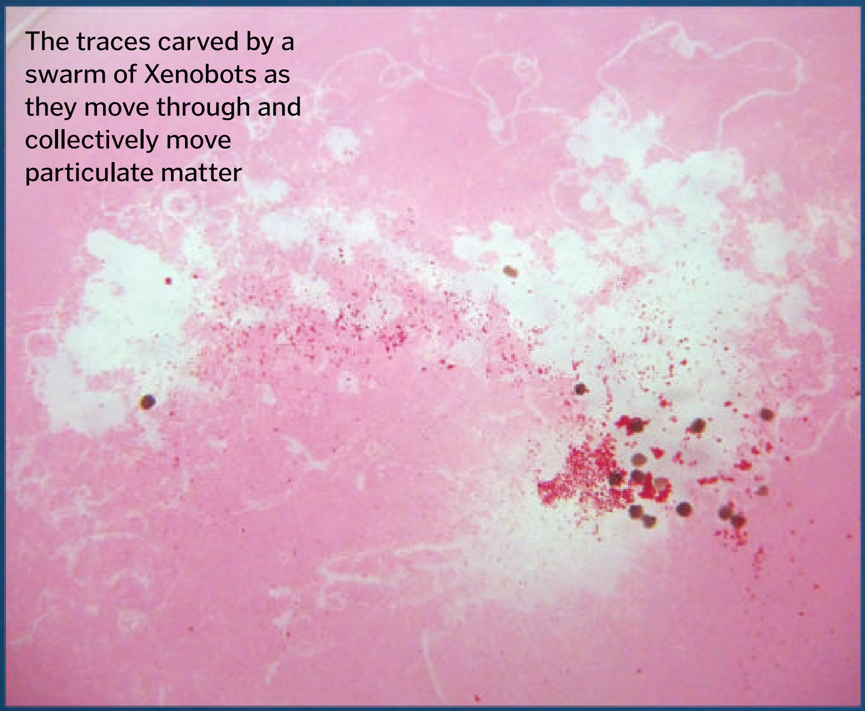
Called 'Xenobots', these spongy cloud-like living robots consist of biological stitchings of different types of cells collected from the surface of a developing frog embryo. One of the reasons that frog cells were used in this study was due to a natural energy source that allows them to survive around ten days in a water solution during the experiment.

The cells collected from the frog embryos were developing stem cells, which have the potential to diversify into many other types of cells. By scraping cells at particular locations on the embryos' surface or exposing them to different chemical or genetic treatments in the laboratory, researchers were able to determine what types of cells they became. In the case of the Xenobots, passive skin and cardiac muscle cells were required.

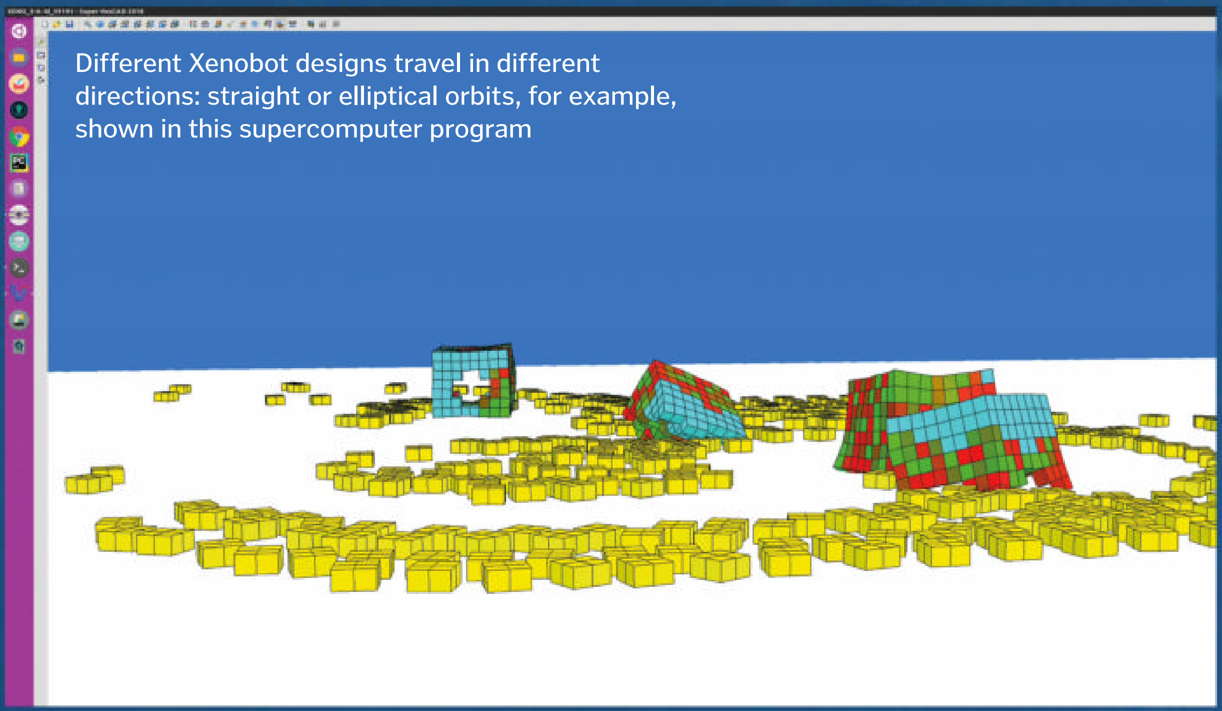
In its infancy as a scientific concept these living machines were not designed to carry out complex or stimulus tasks, but rather to simply survive and move. It's the cardiac muscle cells that give the Xenobots their ability to move through contraction and relaxation in the same way they facilitate a heartbeat.

One of the challenges of making a living machine lies in knowing how to arrange each of the cellular building blocks. However, collaborating with the University of Vermont, researchers ran an evolutionary algorithm through a supercomputer, which then generates different configurations of these cells to produce the optimal Xenobot based on a desired set of attributes. For example, one of the most robust forms tested out by the research team was one commonly seen in nature: a leg at the front and at the back with contacting cardiac muscle cells in between. As the cardiac muscles contract, they pull the legs together and then release them. This makes the Xenobot move in a way reminiscent of how a caterpillar or worm might crawl along a branch.

> "Cardiac muscle cells give the Xenobots their ability to move through contraction"



The traces carved by a swarm of Xenobots as they move through and collectively move particulate matter



Different Xenobot designs travel in different directions: straight or elliptical orbits, for example, shown in this supercomputer program

## Q&A Meet the man behind the machines

Co-author Dr Douglas Blackiston explains the unpredictability of Xenobots and how we can use them in the future

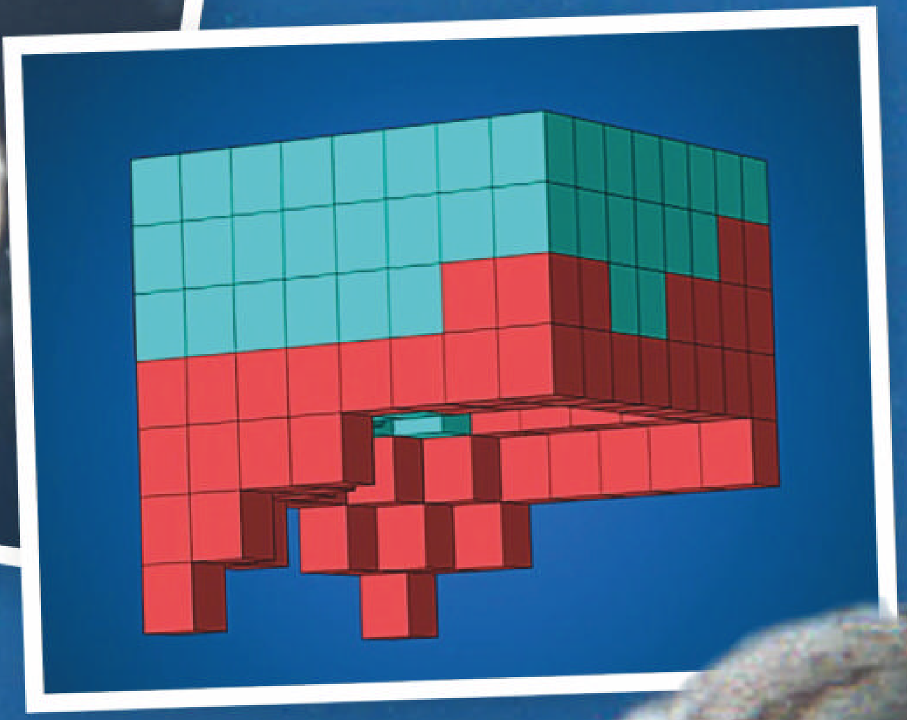
**How do you control how the Xenobots move while in a solution?**

That's up to the Xenobot. I wish I could say I had a lot to do there, but you put them in the solution and then based on the physics of their movement system and the way they've been patterned, they do all of these things on their own. We have no understanding right now if it's something under their control and something they're doing intelligently or if that's some by-product of their physiology. We're looking at ways to control that. We have in biology the ability to control muscles

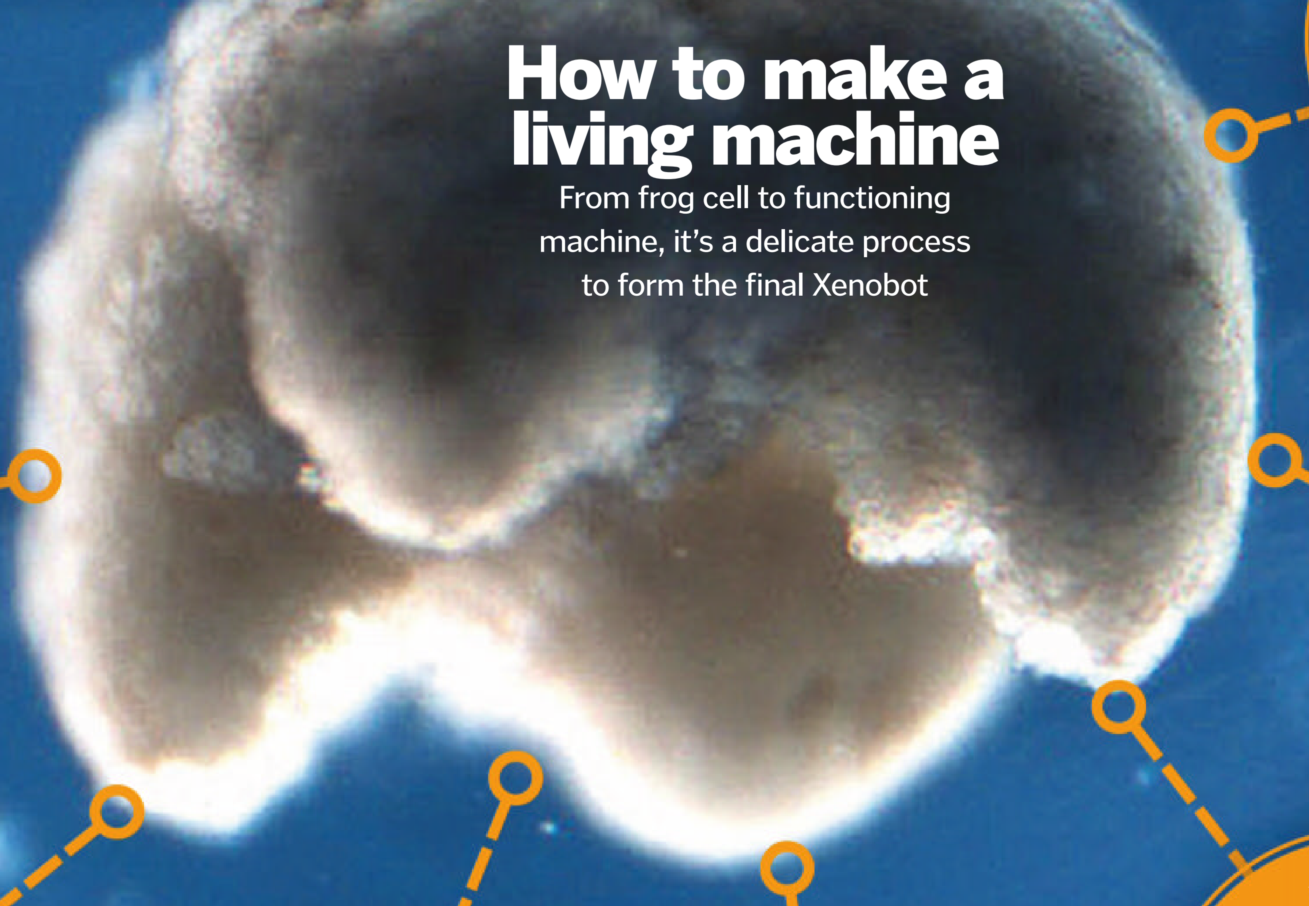
**DID YOU KNOW?** *Xenobots are named after the African clawed frog (Xenopus laevis) from which they take their stem cells*

# How to make a living machine

From frog cell to functioning machine, it's a delicate process to form the final Xenobot



Stem cells need to become the right building blocks



## 1

### Biological blueprints

A supercomputer compiles different coloured blocks, attributed to different cells, to work out the order and placement of these cells needed to create a Xenobot that can carry out a particular function.

## 2

### Stem cell collection

A micro cautery wire, about 13 microns in width, is scraped off the very top of the developing embryo.

## 3

### Cell separation

The collected stem cells are then placed in a medium of low calcium and magnesium, two atoms necessary to hold the cells together during sculpting.

## 4

### Agitation

When this solution is agitated, this collection of cells individually separates.

## 5

### Becoming a specialist

Lone stem cells are then gathered. By using a chemical or genetic treatment they can be guided to become different cell types.

## 6

### Holding cell

Individual diversified cells are held in wells of water for safekeeping until they are used to construct the final Xenobot.

## 7

### Construction

Using a micropipette these cells are sandwiched together and layered by hand based on the simulated model generated by a supercomputer.

## 8

### Sewing cells

In order to get the cells to stick together, the holding solution is swapped for water. In the process all the cells stick together.

## 9

### Finishing touch

Using another micro cautery wire and surgical forceps, the final Xenobot is shaped to make sure that all their cells are in the correct position.

A manufactured Xenobot, 650 to 750 microns in diameter, made from a frog embryo

by shining light, by playing with molecular genetics. You can imagine using a light source or laser and driving these around and activating their muscles in. That's one of the things we've been looking at, but as far as we know this scattering behaviour is a spontaneous phenomenon. We were surprised to see it. But it matched a lot of what we saw in our simulated robot.

**What inspired you to pursue this research and what are its future applications?**
I was really interested in this idea of plasticity. How do you recombine and restructure part of an animal's body and have it still have a functional behaviour, like metamorphosis, for example. You're essentially taking a crawling animal and making it into a flying one. The Xenobots are very different, but it's this idea of taking cells that are made for something like growing a frog and really pushing the limits of plasticity, putting these cells into novel configurations and building something new. But beyond my own interest, this technology is a great sandbox for other scientists to play in. There may be scientists who want to build different shapes for growing human organs, or playing with different tissues and layering them in different ways. The technology that we developed could really be applicable to a lot of different areas, even regenerative. If you lose a finger or an arm, you want to regrow the right amount of tissue in the right place and control how that unpacking happens, and that's very complicated. However, Xenobots, where you can place the cells and grow and shape them, allow us to get into the nitty-gritty of how that process works, and how we get control over that process.

All images © Douglas Blackiston

# Understanding coronavirus

Know your enemy: here are some of the basics behind the pandemic that has paralysed the world

## Infection

### COVID-19

Coronavirus is the name of a group of viruses that affect humans and other mammals. The word 'corona' stems from the Latin meaning 'crown' due to the protruding spikes of proteins on the virus' surface.

### Infection

The virus enters the body through droplet transmission, whereby fluid produced by an infected person – such as spit – enters the mouth or nose of another.

### Travel

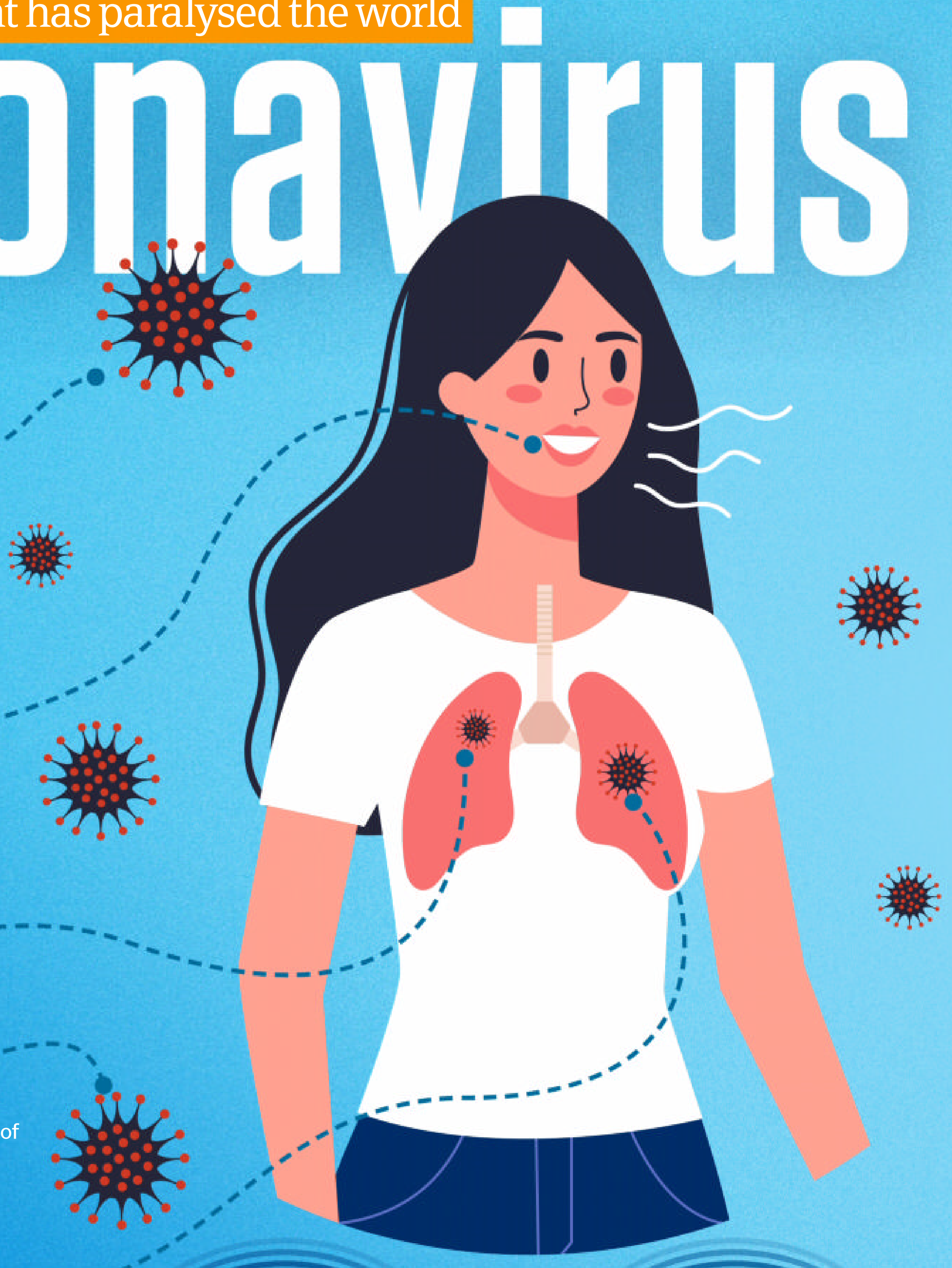
Once in the body, COVID-19 moves down the mucus membrane in the throat towards the lungs.

### Hijack

The spiky proteins on the surface of the virus hook onto cells in the lungs, injecting chemical instructions into them that force them to make copies of the virus.

### Immune response

After detecting the viral intruder, our immune system will begin to fight against the virus. In some severe cases this battle can lead to fluid building in the lungs and difficulty in breathing.



Transmission

### Coughing and sneezing

Tiny droplets are released into the air when you cough or sneeze. If any infected droplets are inhaled by another person they will also become infected.

Transmission

### Touching surfaces

COVID-19 can survive on surfaces for a few hours up to several days. Touching an infected surface and then touching your face can transmit the virus between people.

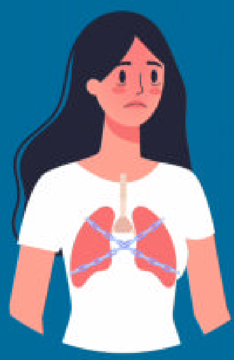
## Symptoms

### Fever

Feeling hot to touch, particularly around your chest or back, could be an indication of infection.

### Persistent coughing

Coughing heavily for more than an hour, or three or more coughing episodes within 24 hours.



### Shortness of breath

COVID-19 can affect the respiratory system, leaving those who are infected short of breath and in severe cases requiring the assistance of a ventilator.

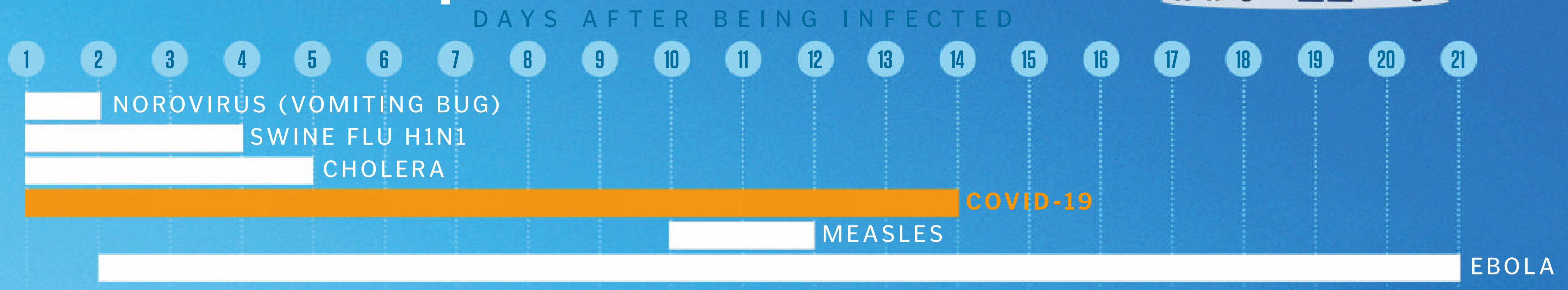
## Myths busted

- Rinsing your nose with saline will not prevent infection
- 5G does not spread the coronavirus
- Coronavirus is not a lifelong disease

**DID YOU KNOW?** *At the time of writing, over 3 million people have been infected by coronavirus worldwide*

# Incubation period

The length of time taken from exposure to the virus to developing symptoms



# Prevention

## Wash your hands for 20 seconds

Cleaning your hands after touching surfaces or leaving the home will help to remove any COVID-19 droplets you may have collected on your hands that can transmit the virus.

## Cover your nose and mouth

Using a cloth or mask will block droplets from dispersing into the air, helping to prevent potential transmission of the disease.

## Avoid touching your face

By not touching your face you prevent the virus from reaching your mouth and nose, where it can enter the body.

## Clean surfaces

Much like washing your hands, cleaning surfaces around the home will prevent others from accidentally picking up the virus.

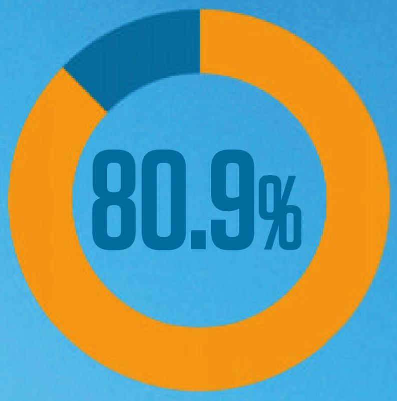
## Keep your distance

Remaining two metres away from others outside your home will reduce the risk of coming into contact with airborne droplets containing the virus.

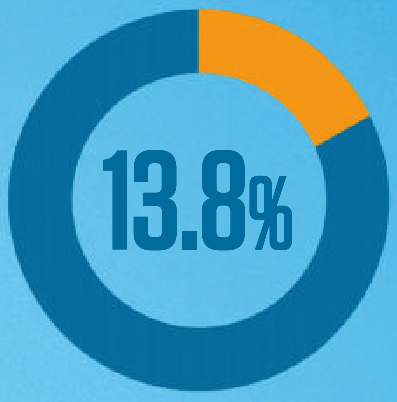
## Stay home

Ultimately, stay at home. The less time you spend outside where you might encounter the virus, the greater the chance you have of avoiding infection.

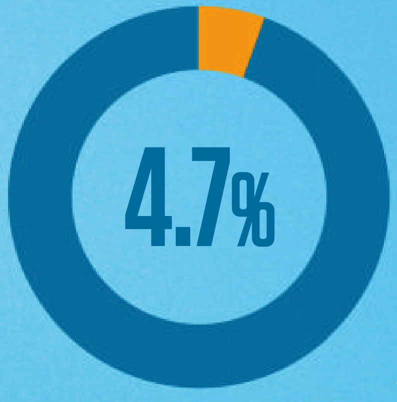
## Severity of symptoms around the world



**MILD**
Those experiencing flu-like symptoms at home



**SEVERE**
Those admitted into hospital for treatment



**CRITICAL**
Patients moved into intensive care

✗ The transmission of COVID-19 is not prevented by hot weather

✗ People of all ages can be infected with the virus

✗ Antibiotics do not work against viruses, only bacteria

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# What are E numbers?

## How to decode the additives in your food

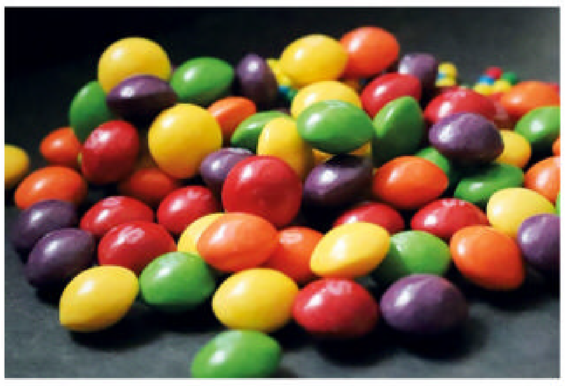
Additives are more likely to be found in processed foods

Ancient Romans added saffron to their food for spice and colouring

There are thousands of additives used in food, ranging from coloured spices to acid preservatives. With some being much more harmful than others, how are you supposed to differentiate between them? Chemicals can have such complex names that you can read the back of a crisp packet and be none the wiser to what it is you're actually eating.

E numbers are the codes given to these additives, helping to categorise them based on their characteristics. Each category provides a different purpose for the food they are added to. This numbering system was put into place in the 1960s, with each additive given a unique number based on its properties. These are prefixed with an E for Europe, but many countries outside of Europe simply use the number. One example is aluminium, which is given the code E173. The numeric part begins with a 1, indicating that the additive is used as a food colouring. In this case it gives a silvery shine to food, sometimes seen on sugary confectionery.

Some E numbers are deemed necessary to give foods the characteristics that make them appealing, but negative health impacts can be hidden behind the coded letters.



## Food colours (E100-E199)

E numbers in this category are incorporated to change the food's appearance. Food colourings are common in sweets to differentiate between flavours and to make them look appealing to children. Some of these ingredients are more healthy than others, such as curcumin (E100).

**E220: sulphur dioxide is used to preserve the grapes and prevent wine from turning into vinegar**

**E202: potassium sorbate stops yeast from spoiling in the wine-making process**

## Preservatives (E200-E299)

Added ingredients in this category are used to stop food or drink from spoiling. To achieve this they fight off any bacteria, mould, fungus and yeast. Without them foods would have a shorter shelf life, becoming an unsuitable colour, texture or flavour much more quickly.

**E325: sodium lactate acts as an acidity regulator**

**E322: as a fatty substance found in soybeans, soy lecithin is used to bind ingredients but also contains antioxidant properties**

## Antioxidants (E300-E399)

As the name suggests, antioxidants reduce oxidation. This process would break down oxygen into atoms and unpaired electrons called free radicals. Vitamin C is one of the E numbers that prevents this, stopping free radicals from damaging cells in the food.

**E442: ammonium phosphatides can be made synthetically using glycerol and rapeseed oil**

**E466: this cellulose gum is often added to the mix to thicken up the mayonnaise**

**E460: microcrystalline cellulose is another term for wood pulp. This is used in some low-fat mayonnaise to replace the fat**

## Thickeners, emulsifiers and stabilisers (E400-E499)

This category has variable properties. In foods such as soups and sauces, E numbers can create a good consistency. Meanwhile, emulsifiers and stabilisers are added to foods that need to keep oils and water from separating.

**E500: baking soda is also known as sodium bicarbonate. This reacts with acid to increase the volume of foods such as cakes while lightening the texture**

## Acidity regulators and anti-caking agents (E500-E599)

Acidity regulators help to control the pH of foods, while anti-caking agents are frequently used in powdered foods to absorb excess moisture and stop lumps from forming.

**E621: monosodium glutamate is one of the most common flavour enhancers in foods. It brings out the savoury or meaty flavours**

**E631: disodium inosinate works with E621 to create the umami – or savoury – taste**

## Flavour enhancers (E600-E699)

Flavour-enhancing additives are usually added to processed foods to make them taste nicer. May fast-food restaurants and take-aways are thought to use flavour enhancers in some way, also helping to make them more addictive.

**E954: saccharin can have a bitter aftertaste but can make a fizzy drink 200 to 700 times sweeter than if granulated sugar is used**

**E951: aspartame is a sweetener that is 200-times sweeter than granulated sugar**

## Sweeteners, foaming agents and gases (E700-E999)

The additives found in these categories hold a broad range of purposes. For example, nitrogen gas is often added to crisp packets to keep them fresh and stop them from oxidising.

## Colours of hyperactivity

These food colourings stimulate childrens' nervous systems and are linked to hyperactivity

E102

### Tartrazine

Found in foods such as custard, marzipan and soup, this lemon-yellow dye is one of the most common food colour additives.

E104

### Quinoline Yellow

This additive is banned in Norway, America, Austria and Japan for health reasons. The colour is believed to cause inflammation of the skin called dermatitis.

E110

### Sunset Yellow

Common in orange squash, cakes and Irn-Bru, E110 is not recommended for children. The dye, which is made from petroleum, can cause abdominal pain.

E122

### Carmoisine

E122 is a product of coal tar and is banned in many countries due to its carcinogenic properties. You can still find it in items like sweets and jellies in the UK.

E124

### Ponceau

Ponceau is a common ingredient in salami, seafood dressings, trifles and processed fruits. Hyperactivity is the main risk when ingesting this E number.

E129

### Allura Red

Also known as Red 40, it's often found in cheese, salad dressings, cereals and marshmallows. To avoid this colouring some companies now use natural sources such as beets and purple sweet potatoes.

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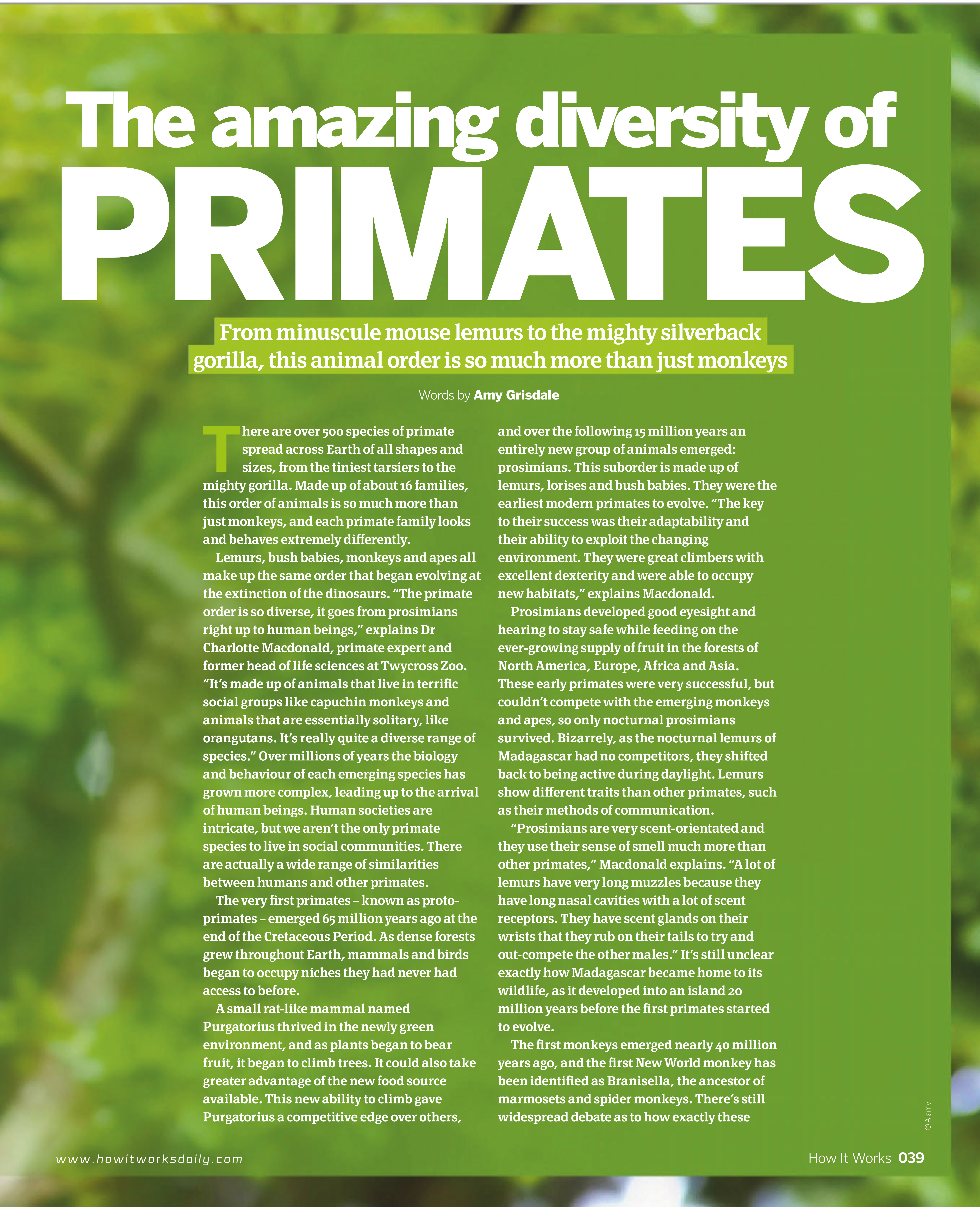

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# The amazing diversity of PRIMATES

From minuscule mouse lemurs to the mighty silverback gorilla, this animal order is so much more than just monkeys

Words by **Amy Grisdale**

There are over 500 species of primate spread across Earth of all shapes and sizes, from the tiniest tarsiers to the mighty gorilla. Made up of about 16 families, this order of animals is so much more than just monkeys, and each primate family looks and behaves extremely differently.

Lemurs, bush babies, monkeys and apes all make up the same order that began evolving at the extinction of the dinosaurs. "The primate order is so diverse, it goes from prosimians right up to human beings," explains Dr Charlotte Macdonald, primate expert and former head of life sciences at Twycross Zoo. "It's made up of animals that live in terrific social groups like capuchin monkeys and animals that are essentially solitary, like orangutans. It's really quite a diverse range of species." Over millions of years the biology and behaviour of each emerging species has grown more complex, leading up to the arrival of human beings. Human societies are intricate, but we aren't the only primate species to live in social communities. There are actually a wide range of similarities between humans and other primates.

The very first primates – known as proto-primates – emerged 65 million years ago at the end of the Cretaceous Period. As dense forests grew throughout Earth, mammals and birds began to occupy niches they had never had access to before.

A small rat-like mammal named Purgatorius thrived in the newly green environment, and as plants began to bear fruit, it began to climb trees. It could also take greater advantage of the new food source available. This new ability to climb gave Purgatorius a competitive edge over others, and over the following 15 million years an entirely new group of animals emerged: prosimians. This suborder is made up of lemurs, lorises and bush babies. They were the earliest modern primates to evolve. "The key to their success was their adaptability and their ability to exploit the changing environment. They were great climbers with excellent dexterity and were able to occupy new habitats," explains Macdonald.

Prosimians developed good eyesight and hearing to stay safe while feeding on the ever-growing supply of fruit in the forests of North America, Europe, Africa and Asia. These early primates were very successful, but couldn't compete with the emerging monkeys and apes, so only nocturnal prosimians survived. Bizarrely, as the nocturnal lemurs of Madagascar had no competitors, they shifted back to being active during daylight. Lemurs show different traits than other primates, such as their methods of communication.

"Prosimians are very scent-orientated and they use their sense of smell much more than other primates," Macdonald explains. "A lot of lemurs have very long muzzles because they have long nasal cavities with a lot of scent receptors. They have scent glands on their wrists that they rub on their tails to try and out-compete the other males." It's still unclear exactly how Madagascar became home to its wildlife, as it developed into an island 20 million years before the first primates started to evolve.

The first monkeys emerged nearly 40 million years ago, and the first New World monkey has been identified as Branisella, the ancestor of marmosets and spider monkeys. There's still widespread debate as to how exactly these

The long limbs and prehensile tail of the black-headed spider monkey help it swing between branches

© Alamy

© Getty

Cotton-eared marmosets live in the edge of forests and have sharp claws for gripping trees

monkeys populated South America – hence 'New World' – but it's widely believed early primates hitched rides across the ocean on floating islands or driftwood thatches. The continents were still slowly drifting apart at this time, making the journey across the Atlantic Ocean much shorter.

Branisella had sharp teeth and a prehensile tail – an important trait found in monkeys that prosimians and apes don't share. This tail was the key to treetop survival. "Their prehensile tails gave them an extra limb," Macdonald tells us. "The development of the tail allowed them to move fast through the thick tree canopy and use both hands while relying on their tail for balance. For example, if trying to crack a nut, they could anchor themselves with the tail and crack the nut with both free hands."

It's clear from fossil records that 33 million years ago the first ancestors of Old World monkeys were emerging. These primates walked on all fours and had ridged molars like modern monkeys. Within 15 million years several monkey species with cheek pouches, similar to modern-day baboons, fed on leaves and roamed throughout Europe and Africa. These gave rise to larger primates like rhesus monkeys, macaques and baboons.

> "The first New World monkey has been identified as Branisella, the ancestor of marmosets and spider monkeys"

Even though they all bear many similarities, there are several differences between the monkeys found on different continents. "A lot of the differences are anatomical. Old World monkeys have central nostrils that point downwards, whereas New World monkey nostrils point sideways, giving them the name platyrrhine monkeys, meaning flat nose. The majority of Old World monkeys have opposable thumbs, whereas New World monkey thumbs lie in line with the rest of the fingers, so they have more of a scissor grip."

A primate called Propliopithecus was established in northern Africa around 30 million years ago and is believed to have been the first true ape. It resembled a small gibbon, which were the first modern apes to evolve. Apes and monkeys are very different animals. "Monkeys have tails, and tend to be smaller than apes. Gibbons, chimps and other apes have flatter chests than the rounded torsos seen in monkeys," Macdonald explains.

During the Late Miocene – starting around 11 million years ago – an abundance of apes emerged that unfortunately are no longer around today. Gigantopithecus, for example, was twice the size of a modern gorilla. Animals such as this were the ancient ancestors of gorillas and orangutans, which are in different subfamilies to hominids. These include chimpanzees, bonobos and even us humans. However,

## Different primate groups at a glance

This scientific order contains hundreds of animals, from the minute pygmy mouse lemur to the mighty silverback gorilla

© Getty

**OLD WORLD MONKEYS**

Proboscis monkey
Snub-nosed monkey
Hamadryas baboon
De Brazza's monkey
Red-shanked douc

Cercopithecidae, African or Old World monkeys are a family of primates that live across Africa and Asia. Consisting of around 130 species, a lot of these have specialised cheek pouches to help digest starchy fruits and vegetables.

© Getty

**NEW WORLD MONKEYS**

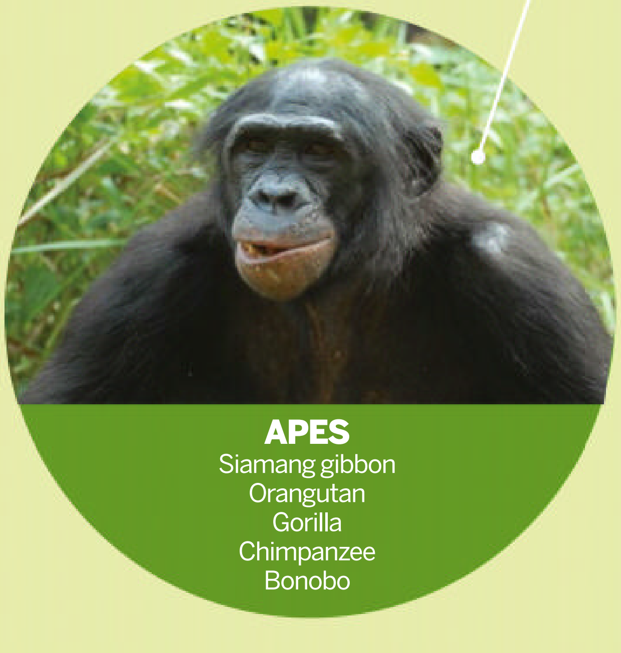
Bald uakari
Howler monkey
Woolly monkey
Emperor tamarin
White-throated capuchin

These small monkeys inhabit central and South America. They are mostly tree dwellers that can move rapidly between trees with their muscular tails and feed on pulpy fruit. They evolved from only a few ancestors that first arrived in South America 40 million years ago.

**LEMURS & BUSH BABIES**

Brown mouse lemur
Slow loris
Lesser bush baby
Coquerel's sifaka
Red-ruffed lemur

Known as prosimians, these feed on fruit and seeds in tropical forests and are mostly nocturnal. True lemurs are only found in Madagascar, but lorises and bush babies are found on mainland Asia and Africa.



**APES**

Siamang gibbon
Orangutan
Gorilla
Chimpanzee
Bonobo

Hominoidea, or apes, are large, tailless and evolved most recently of all the primates. They are highly intelligent and have elaborate social interactions, though many ape species existed and are now extinct due to extreme competition from other apes.

**DID YOU KNOW?** *A howler monkey's powerful howl can travel around 4.8 kilometres through dense rainforest*

# Primates: from the beginning

The 65-million-year journey, from the smallest rat-like mammals to the societies of modern apes

**65 MILLION YEARS AGO**

### Purgatorius (proto-primate)

These were the common ancestors of modern mammals. As Purgatorius filled different niches, over millions of years various animals began to emerge.

**47 MILLION YEARS AGO**

### Prosimians

Lemurs and bush babies evolved to live in trees and feed on fruit. They stayed safe from predators as they were active at night. These animals have survived so long as they are mostly confined to Madagascar with very few natural predators to worry about.

Aye-aye

**40 MILLION YEARS AGO**

### New World monkeys

Small New World monkeys like the common squirrel monkey began to thrive in the jungles of South America after their ancestors made the journey across the Atlantic Ocean over 40 million years ago. Since then hundreds of species have evolved and are seen in their modern forms today.

Squirrel monkey

© Getty

**33 MILLION YEARS AGO**

### Old World monkeys

The monkeys that remained on mainland Africa began to develop cheek pouches and spent more time on the ground than their relatives across the Atlantic. The animals that emerged from these 33 million years ago gave rise to modern baboons and mandrills.

Mandrill

© Getty

**30 MILLION YEARS AGO**

### Lesser apes

The first apes took shape in the rainforests of southeast Asia in the form of gibbons. They walked on two legs and used their long arms to move from branch to branch in the absence of a useful tail.

White-cheeked gibbon

© Getty

**13 MILLION YEARS AGO**

### Ponginae

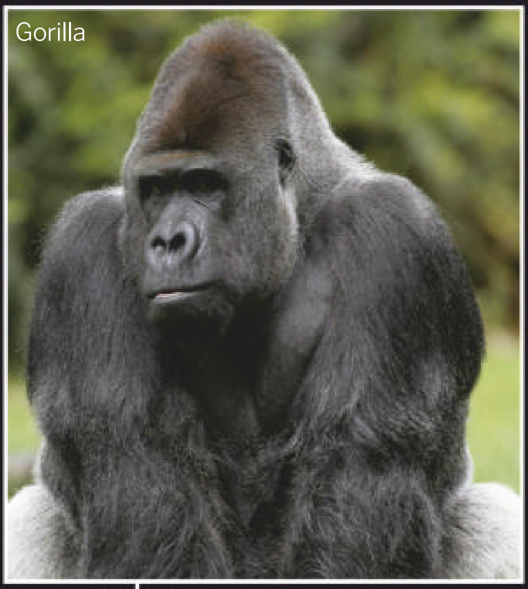
Apes that migrated from Africa to Asia 13 million years ago gave rise to orangutans, which look and behave differently to modern African apes. They became better adapted for their environments.

Bornean orangutan

© Getty

### Gorillinae

The largest living primate is the gorilla, which began to populate Africa 11 million years ago. While there were once more gorilla species, only four subspecies populate the Earth today.



Gorilla

© Getty

**8 MILLION YEARS AGO**

### Hominins

Chimps share 99 per cent of DNA with humans and were the first hominins to evolve. This subfamily eventually gave rise to humans. Every member of the group evolved from a now-extinct ape that lived 8 million years ago.

Chimpanzee

© Getty

**2 MILLION YEARS AGO**

### Human ancestors

Bonobos became a separate species from chimpanzees around 2 million years ago. These are closely related to humans. In recent history there were many other human-like ape species that didn't survive to modern times.

Bonobo

© Getty

Baboons are sociable animals and live in troops, like this yellow baboon family crossing a stream
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Despite being the biggest apes on the planet, gorillas have a completely herbivorous diet

> "There are several differences between the monkeys found on different continents"

hominids didn't appear until 8 million years ago, and humans first emerged in our modern form only 100,000 years ago.

Since ancient times humans have developed complex societies, but we are not the only primates to live in structured social groups and communicate in complex ways. "The basics of ape behaviour are very similar actually. If apes are upset with each other they will fight, if they are happy with each other they will groom or play, but by carefully studying the details of their behaviour reveals them to be very different," Macdonald explains.

Orangutans live in different social structures than other ape species. "The orangutan family unit usually consists of a female with up to two offspring. Male orangutans live completely separately and only seek out females to mate when they are in season." Females and young orangutans live in family groups where the adults spend time together and related young frequently play with one another. Unknown orangutans are treated with suspicion, and young aren't allowed to play with the young of a strange adult. Female orangutans settle next to neighbouring apes they can trust, and each orangutan announces to the group when they are going to sleep.

"Gorillas live in family groups led by a dominant male, commonly known as a silverback," explains Macdonald. Groups with more than one male attract and retain more females, while females decide when it is time to copulate. Lowland gorilla groups contain only one dominant silverback who fiercely protects the females and young apes.

Chimpanzees and bonobos do share common ancestors, but 2 million years ago these apes were separated by the Congo River. By 900,000 years ago they became two entirely distinct species, and although they look incredibly alike, they behave differently in the wild.

Female bonobos have close relationships, and the males don't fight over females. Their communities can be dominated by females and are more peaceful than those of chimpanzees. "Bonobos show a lot of sexual behaviour. This is not just used for mating; they use it as a bonding activity, as reassurance, and they will also use sexual behaviour to resolve arguments," reveals Macdonald.

In contrast, a single male chimp dominates each community, using aggression to defend his status. Females don't associate closely, but males form strong coalitions. "To bond, chimps will groom and play," explains Macdonald. "Bonobos play and groom, but they will use sexual behaviour for the same purpose – to become friends."

Despite their startlingly similar appearance, Macdonald tells us the two species are difficult to compare. "It's like comparing cats and dogs – they are completely different species," she confirms.

Baby orangutans learn from their mothers, staying with her for at least six years

© Getty

Lar gibbons communicate vocally and are known to duet to warn off neighbours posing a threat
© Getty

**DID YOU KNOW?** *At the tip of a monkey's tail is a patch of bare skin that acts in a similar way to a human's fingertips*

# Chimp vs bonobo

Though they share nearly 99 per cent of their genetic material, chimpanzee and bonobo societies couldn't be more different

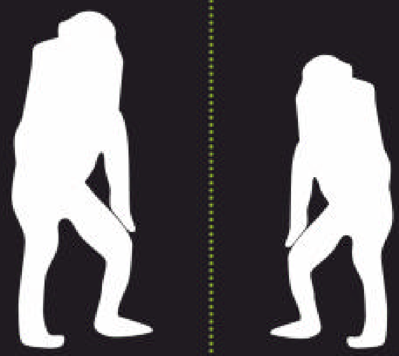
© Corbis

## Chimpanzee
***Pan troglodytes***

Average male weight
**60 kilograms**
Average male height
**1.5 metres**

## Bonobo
***Pan paniscus***

Average male weight
**40 kilograms**
Average male height
**1.2 metres**



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### Taking the lead
Rather than answering to a dominant male, female bonobos become leaders of their group. Chimpanzee groups are always led by males, and each group has an alpha male that takes the top spot among the rest.

### Resolving conflicts
Chimpanzees will shout, threaten and fight others to resolve a conflict that arises, while males use intimidation to get their way. Bonobo disagreements are settled peacefully with social grooming or sexual behaviour.

### Promiscuity
Only the highest ranking male chimpanzees are allowed to mate, and females are heavily guarded to make sure no lower ranks have access. Bonobos use sex as a greeting and to strengthen social bonds within the group.

### Strong alliances
Female bonobos are close with other females and their offspring, but female chimps don't tend to team up and often show aggression. Male chimpanzees form strong alliances with others, but rarely bond with females.

# Why the Earth has magnetic poles

Extraordinary geological goings-on in the planet's chaotic core power its polarity

Words by **Jack Parsons**

When a compass points north, what's guiding it? The answer is the magnetic north pole. The compass needle is attracted by this awesome power in the Arctic. This is different from the place we call the North Pole though. It's the tip of a vast bubble of energy that surrounds the whole planet.

While Earth's magnetic field reaches into outer space, it begins about 2,900 kilometres beneath our feet. The planet's outer core is a scorching sea of molten iron and nickel. This is always churning, with liquid metal rising as it heats, then cooling and sinking. The planet's rotation also causes swirling whirlpools to form. As this liquid metal is conductive, this constant motion acts as a dynamo. It generates electricity, producing a magnetic field.

Like an everyday bar magnet, Earth's magnetism concentrates at two ends: one in the far north, and the other south. While the force is strongest at these poles, the invisible field fans out in every direction between these two points, so it's all around us.

Geological evidence suggests that the 'geodynamo' that powers Earth's magnetic field began at least 3,450 million years ago. When the hellishly hot core eventually cools and hardens, the magnetism will fade away – like it did on Mars long ago. While that's billions of years away from happening on Earth, that doesn't mean the magnetic field is stable. Even slight fluctuations in the core's temperature or fluid flows can have very dramatic effects.

First off, it can make the poles move. The magnetic north is currently wandering from Canada towards Siberia – and it's gaining momentum. While it once shifted an average of 15 kilometres a year, since the mid-1990s it's been moving at 55 kilometres a year. The exact cause is uncertain, but a high-speed jet of liquid iron may be to blame.

The strength of the magnetic field also varies, waxing and waning in different parts of the world each year. There are signs that it's been weakening worldwide for 160 years, possibly due to dense rock under Africa interfering with the core.

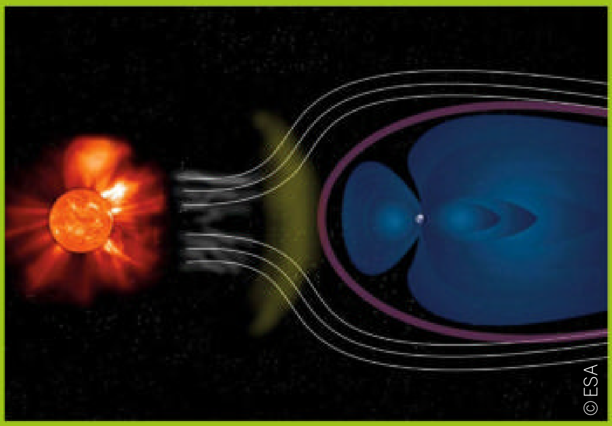
Most incredibly of all, a quirk in the core's chemistry can even make the poles reverse. It's actually happened hundreds of times before – though not for 780,000 years. When it takes place it's not quick either, with the shift taking thousands of years. Future generations might be asking why their compasses always point south instead.

## The planet's protective shield

Earth's magnetic field protects life on Earth from the plasma and particles that constantly spew from the Sun. Without this barrier the 'solar wind' would ravage our atmosphere, starting with the ozone layer that keeps out ultraviolet radiation.

Instead, the magnetic field redirects the charged particles around the planet so that they stream beyond it. But this gust of wind still distorts our magnetic field, compressing the magnetic lines close together on the dayside of Earth and stretching them out into space on the nightside.

Sometimes the Sun releases a larger burst, known as a 'solar storm'. This can overwhelm our protective barrier, but magnetic field lines still funnel these invasive particles to the poles. Here they react with the molecules in the air, so oxygen glows yellow and green. Nitrogen gives off red, violet and occasionally blue. This is the dazzling natural light show we call the aurora.

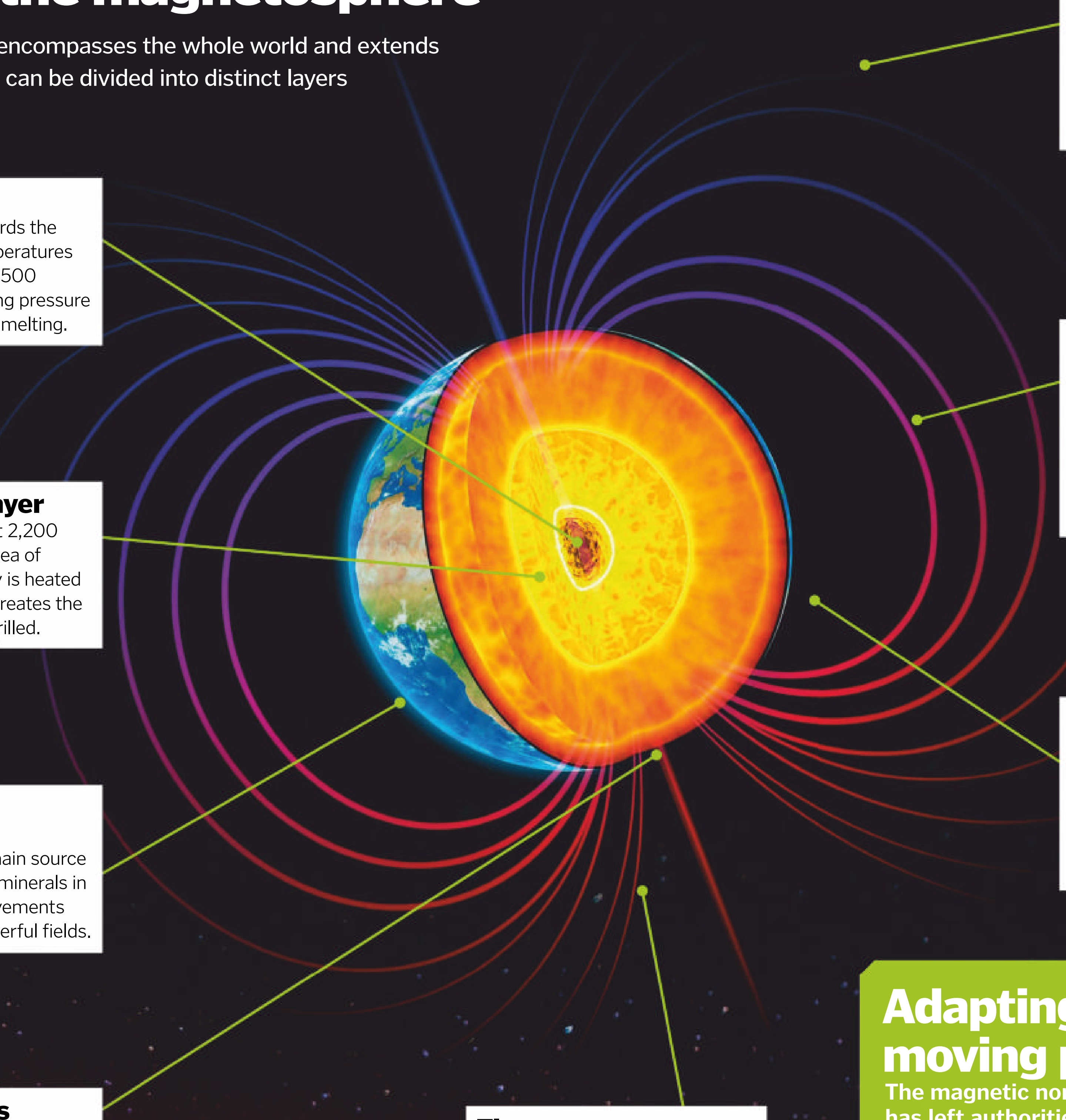

© ESA

The magnetic field deflects the constant stream of dangerous particles from the Sun

A glowing green aurora seen from space, caused by cosmic particles hitting the magnetic field

# Explore the magnetosphere

The magnetic field encompasses the whole world and extends into space, where it can be divided into distinct layers



**The inner core**
Earth's heart is two-thirds the size of the Moon. Temperatures here can reach up to 5,500 Celsius, but the crushing pressure prevents the iron from melting.

**Liquid-metal layer**
The outer core is about 2,200 kilometres thick. This sea of molten iron-nickel alloy is heated by the inner core and creates the magnetic field as it's grilled.

**The motion of the ocean**
While the core is the main source of Earth's magnetism, minerals in the crust and tidal movements also generate less powerful fields.

**Polar opposites**
Like a simple bar magnet, the Earth's magnetic field is a dipole – meaning it has two poles. One's in the north, the other is in the south.

**The bow shock**
The furthest reaches of the magnetosphere act like a hump in the road, forcing the solar wind – often travelling at 500 kilometres per second – to reduce its speed.

**The magnetotail**
While the dayside of the magnetosphere is battered by solar wind, the nightside forms a long tail that can stretch hundreds of times the Earth radius, beyond the Moon's orbit at 60 Earth radii.

**The ionosphere**
Starting about 50 kilometres above the surface, this region is full of atoms that have been stripped of their electrons by the solar wind and cosmic rays. The aurora appears in its upper layers.

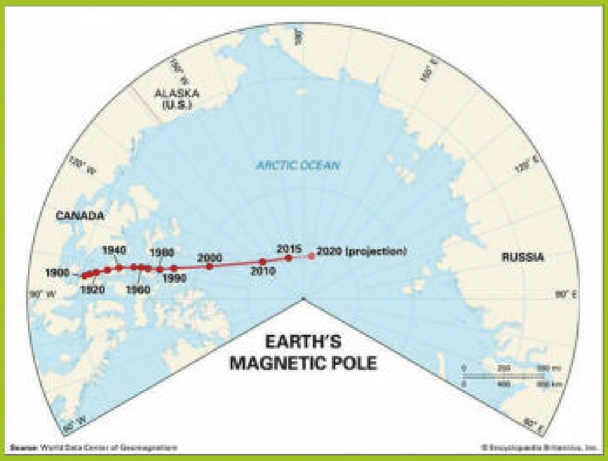
**The magnetopause**
Several hundred kilometres in the air, this is where the solar wind and our magnetic field collide.

© Getty Images/ Andrzeg Wojcick

## Adapting to a moving pole

**The magnetic north pole's speedy drift has left authorities scrambling. Last year they had to update the World Magnetic Model – which is used by military forces and GPS systems on smartphones – a year ahead of schedule. If they hadn't, journeys around the Arctic region could have been disrupted.**

**Many species – including bees, pigeons and turtles – also use magnetism to navigate. The pole's sudden shift might throw off their bearings, so they can't find their breeding grounds or hunting spots. But, like us, the animal kingdom will adapt eventually.**



We've been tracking the magnetic north pole's movements for over a century

© NASA

# Darwin's TRAVELS

## How the father of evolution's five-year voyage changed the way we think about life on Earth

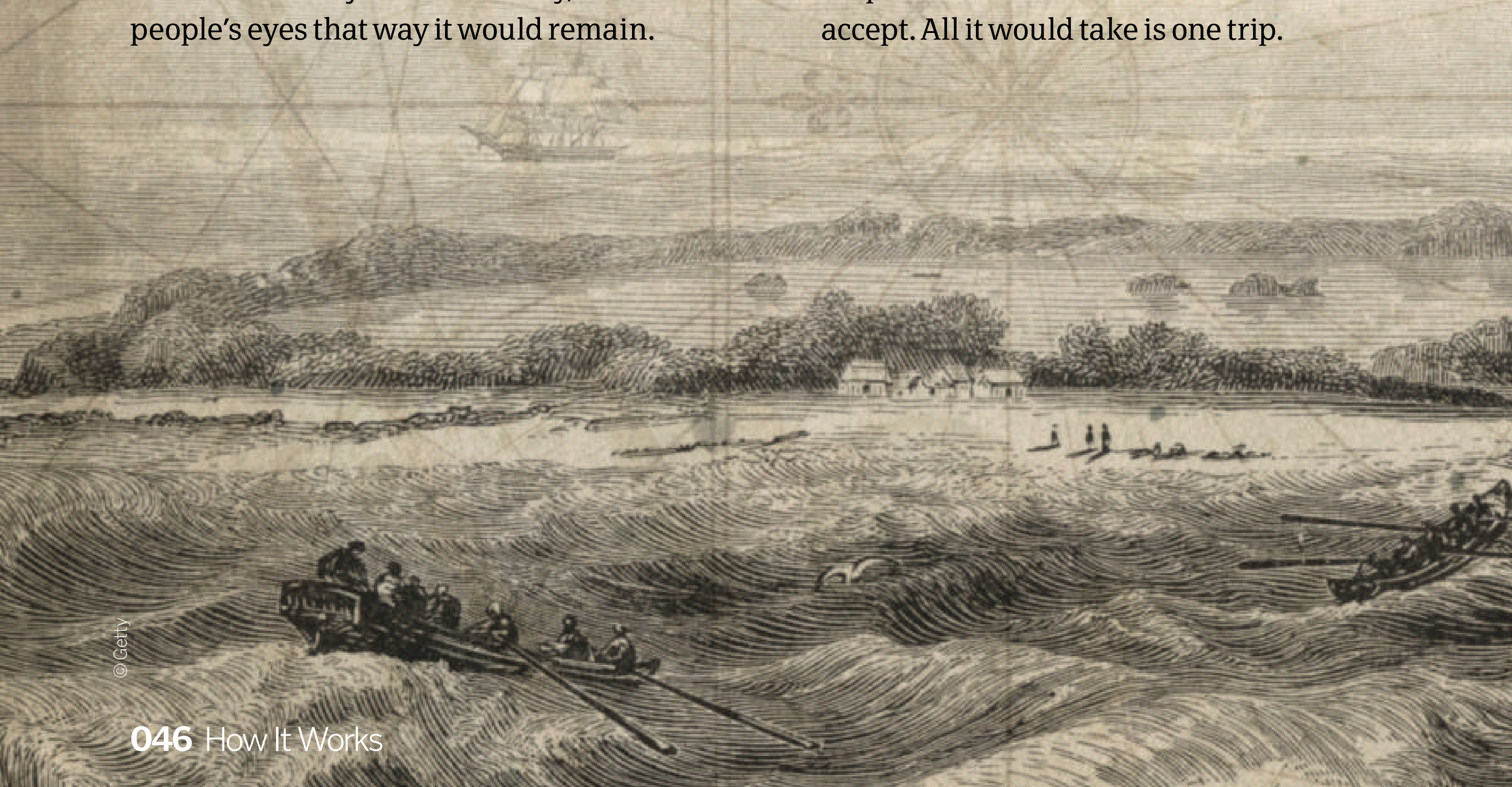
Words by **Ailsa Harvey**

How do you even begin to predict how life on Earth first emerged? As just one of many millions of species living on this planet, humans are a curious one; we are constantly seeking answers to unknown questions. But perhaps the question that gives us the most purpose in life is trying to understand why we are here. What is our history and how did we become the species we are today? Nowadays we are able to open a book or turn to the internet to look for these answers, but it would take a five-year sea voyage nearly 200 years ago to establish the modern understanding of how life on Earth evolved.

Turning the clocks back to the 19th century, ideas about the world were very different to those commonly accepted today. Most people stuck to the belief that the planet's design, and all of its inhabitants, were fixed. The world was the way it was because a creator made it like that. It had always been that way, and in most people's eyes that way it would remain.

Today views are very different. We know that all organisms need to adapt to the environment in which they live. In a continuous competition for survival that sees the strongest species thriving, evolution is an ongoing process with no final destination. This is because Earth is also experiencing constant changes in structure and climate. Many diverse life forms are battling it out for their place in nature. Each and every change in an organism's genetics has helped to create new branches on the tree of life, adding to global biodiversity.

But where did this theory of evolution come from? The answer is in its name – Darwinism. In 1831 a 22-year-old man called Charles Darwin agreed to take part in a trip of a lifetime. Not only would this trip help Darwin forge his future, it would also provide answers to many of the questions dividing scientists at the time. He would provide global evidence about the origin of species on Earth that most would come to accept. All it would take is one trip.



© Getty

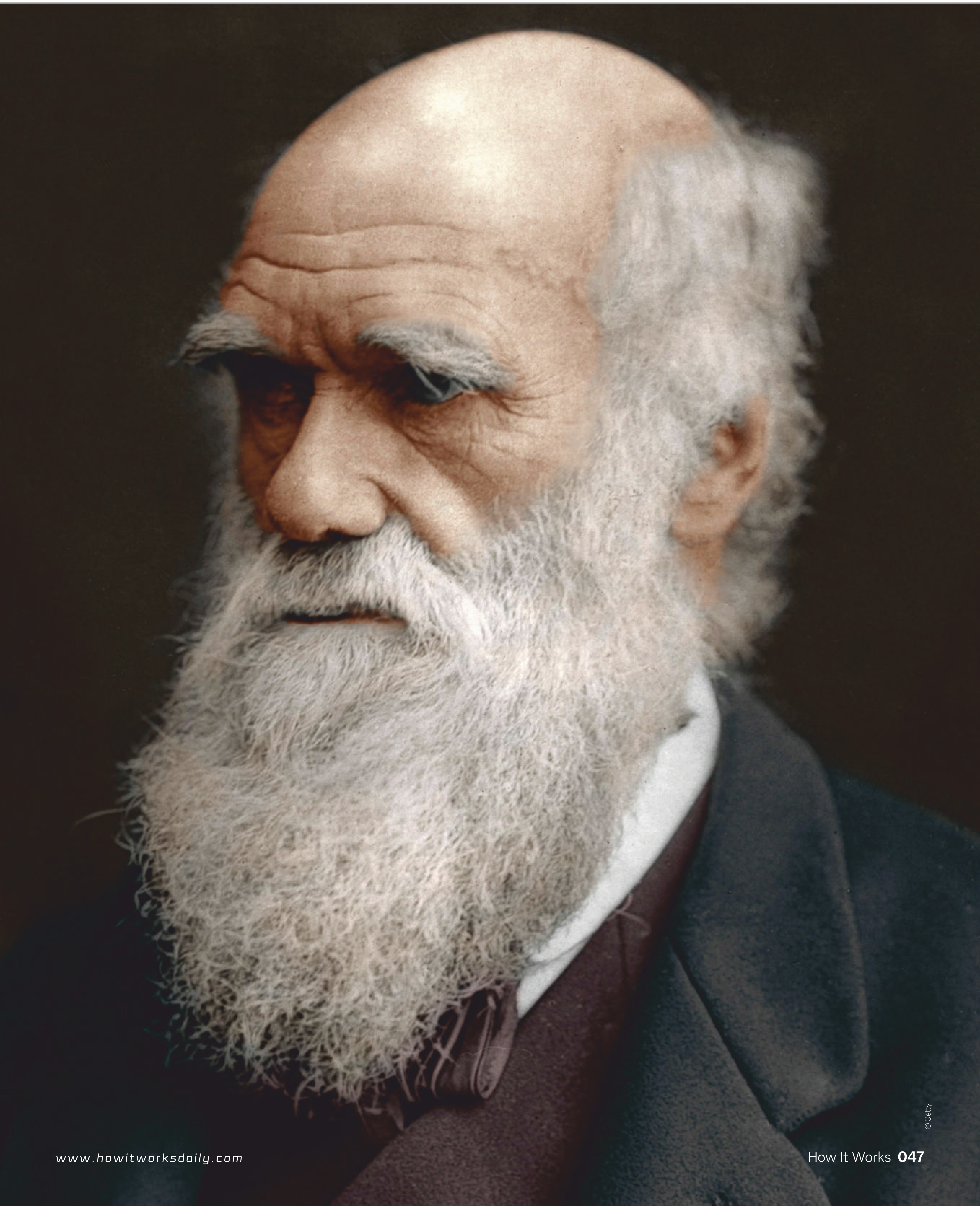
## Before he set sail

**Enrolling at Edinburgh University at 16, Darwin first studied medicine. He soon learned that his passions lay elsewhere. As a student he spent much of his spare time absorbing natural history, and he became fascinated with animal biology.**

**It became clear that medicine was not the future Darwin desired. With lectures failing to enthuse him and having discovered the gruesome nature of surgery, he left the university. Darwin's father arranged his next step. He would become a priest, leaving for Christ's College in Cambridge in 1828.**

**While here his true interests led to him befriending geologist Adam Sedgwick and botanist John Henslow. Freshly equipped with his bachelor of arts, it was as he questioned his future in 1831 that HMS Beagle was organising a round-the-world trip. The ship's captain approached Henslow, asking for his recommendation of a naturalist and companion to join the voyage and embark on the study of a lifetime. There was only one answer: Charles Darwin.**

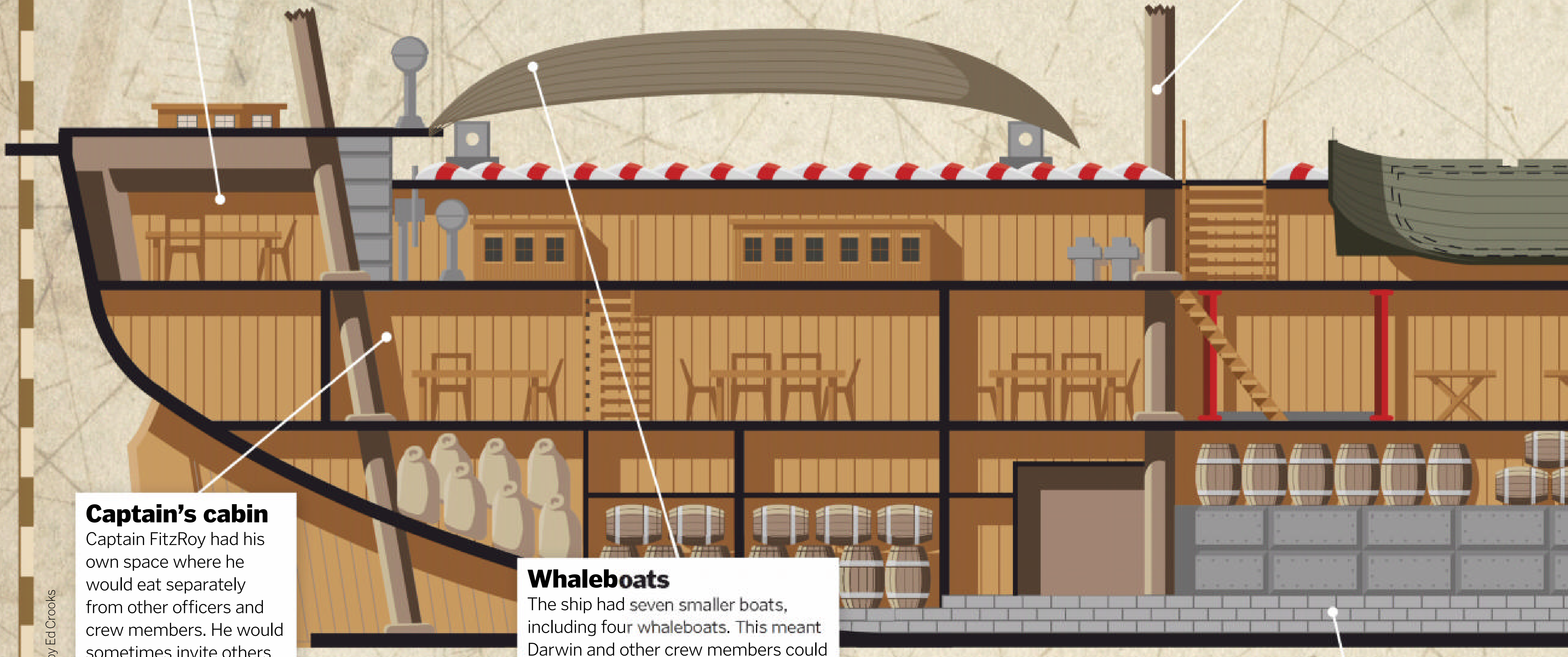
Throughout university, Darwin preferred to lead his own studies



© Getty

# All aboard the BEAGLE

Darwin spent a total of 18 months living at sea



**Poop deck**
This room at the back of the ship was where Darwin spent much of his time. Featuring a skylight, Darwin used this as both his work and sleep area. Being at the back, this room was almost constantly swaying, giving him frequent seasickness.

**Main mast**
Darwin and other crew members helped with rising and lowering the masts, following the captain's orders. In his diary Darwin wrote: "The wind fell and was succeeded by a calm; this is always the worst part of a gale, for the ship, not being steadied by the wind pressing on the sails, rolls in a most uncomfortable manner."

**Captain's cabin**
Captain FitzRoy had his own space where he would eat separately from other officers and crew members. He would sometimes invite others to eat with him, and Darwin often ate here.

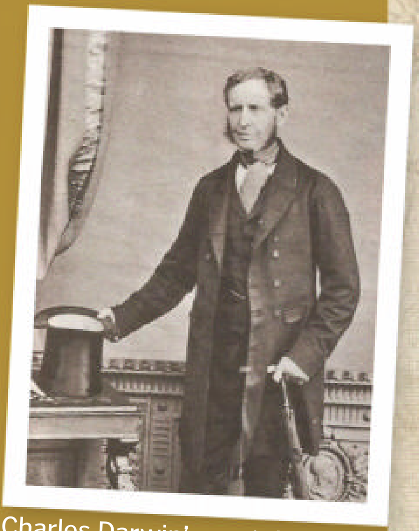
**Whaleboats**
The ship had seven smaller boats, including four whaleboats. This meant Darwin and other crew members could explore sites closer to land before sailing the whole ship to each area.

© Illustration by Ed Crooks

## Ship living

**Like Darwin himself, most of the crew were young men in their 20s. During the long hours at sea, Darwin documented the games that were played to keep spirits high. One game, named 'slinging the monkey', involved tying someone to a frame by their feet and swinging them around until they managed to hit a fellow crew member with a stick. Through all the fun, it is apparent that Darwin kept his research as his main priority. He wrote of his concern about hungover crew members after these celebratory antics.**

**When he wasn't writing letters to friends at home, Darwin was getting to know his acquaintances on board. One of these was John Lort Stokes, both a naval officer and Darwin's cabin mate. They frequently spent evenings working together, Darwin with his microscope and Stokes with his charts for navigating.**

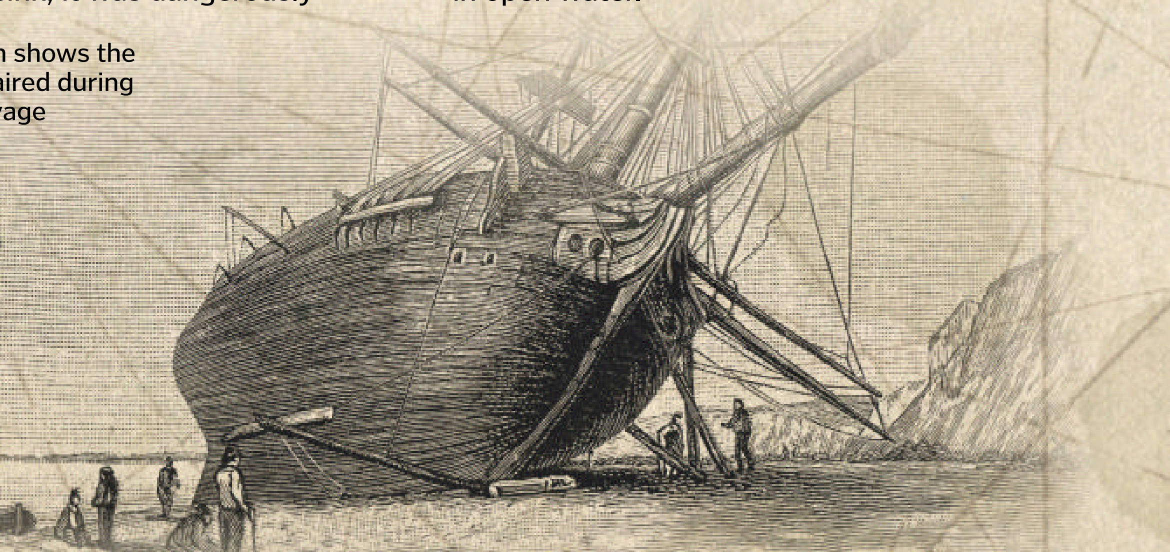


Charles Darwin's captain and friend, Robert FitzRoy

## The primary mission

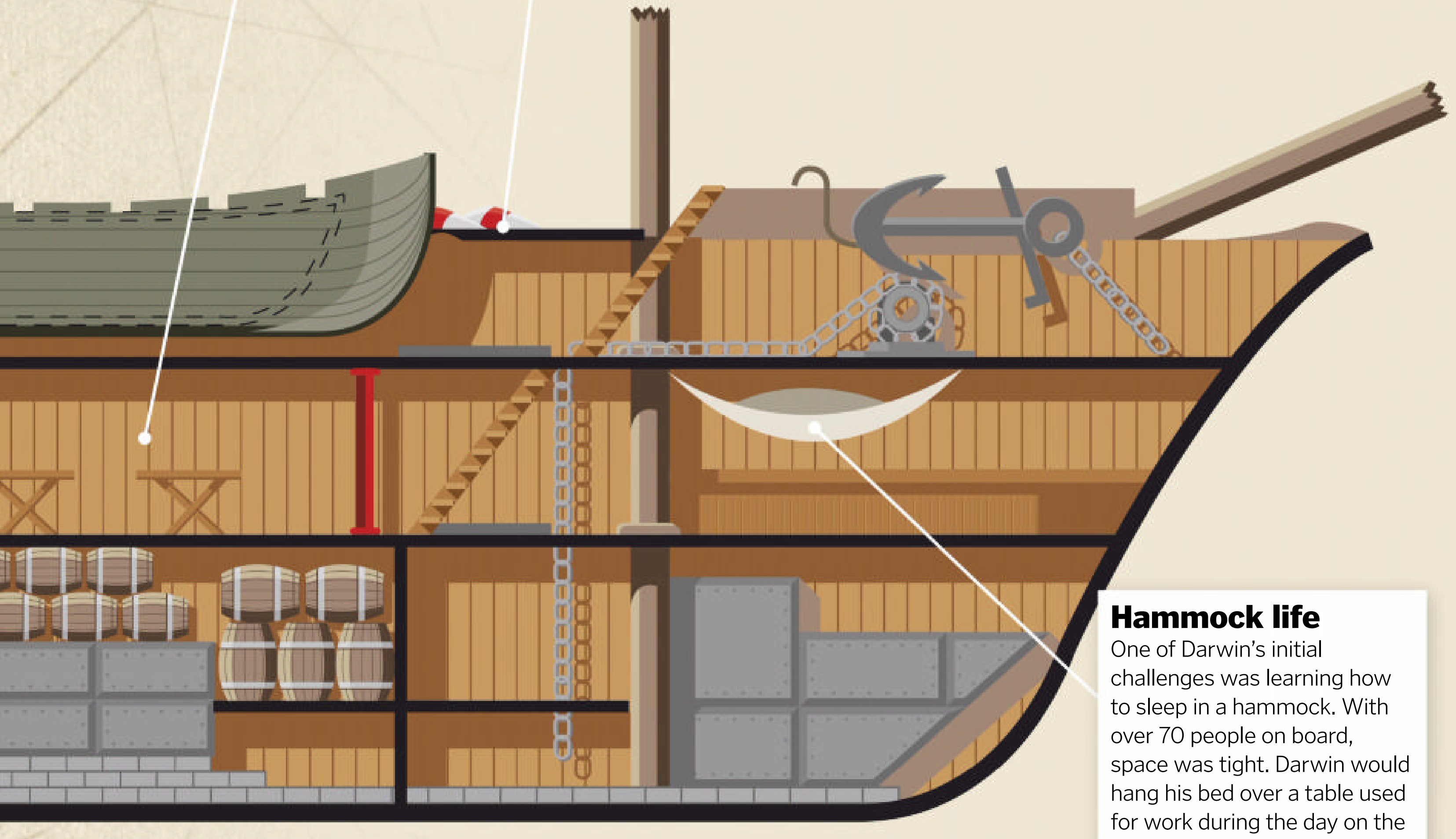
Darwin's voyage was only the second voyage the HMS Beagle had taken. Originally built for Great Britain's Royal Navy, it first set off five years earlier. For Darwin's trip the Beagle was tasked with surveying the physical features of the coasts of South America. The vessel was revamped with a new raised deck and brass guns.

As a Cherokee-class ship, a type of vessel nicknamed 'coffin brig' due to their tendency to sink, it was dangerously top-heavy. Issues of safety and comfort almost stopped Darwin from agreeing to the trip. He was told that if the ship was unsafe, it wouldn't be sent for such an important voyage – and luckily the boat held up for the full five years. Of the three surveying voyages the ship carried out, the second is best documented and most famous. After one more sea-surveying trip the Beagle became a coastguard watch boat, and no longer spent long periods out in open water.



This illustration shows the ship being repaired during the second voyage

**DID YOU KNOW?** *Charles Darwin collected more than 5,000 specimens to help him piece together his findings*



**Mess tables**
This room was for socialising and eating. Darwin was known for eating almost any animal he discovered. A few days after Christmas Day 1833, the ship's cook served a rhea. Halfway through the meal, Darwin realised that he was eating a rare large bird that he had been searching for.

**Length: 27.5 metres**

**Hammock life**
One of Darwin's initial challenges was learning how to sleep in a hammock. With over 70 people on board, space was tight. Darwin would hang his bed over a table used for work during the day on the opposite end of the ship.

> *"He would provide global evidence about the origin of species on Earth"*

## 5 FACTS ABOUT DARWINS AROUND THE WORLD

1 **Darwin Island, Galápagos** The Galápagos Islands fuelled much of Darwin's evidence for evolution. As one of the smallest islands, it is an extinct volcano with a rock feature: Darwin's Arch.

2 **Darwin, Falkland Islands** Darwin is said to have spent the night here. While exploring the Falkland Islands he spent time intrigued by wolves and bird life.

3 **Darwin Sound, Beagle Channel** This stretch of channel in Chile was named by HMS Beagle's captain FitzRoy. Here Darwin used quick thinking to save crew members as falling glacial ice threatened to sweep away their boats.

4 **Port Darwin, Australia** Found in the Australian city of Darwin, the port was given its name by Darwin's former shipmates when they travelled on HMS Beagle's third voyage.

5 **Charles Darwin Research Station, Puerto Ayora** In 1964 a research station in his name was established, allowing continued scientific work and preservation in the area.

## How *On the Origin of Species* was formed

**Returning home in 1836, Darwin was equipped with research that would transform the way the world viewed biology. However, he kept this to himself and waited over 20 years before publishing his findings. Many speculate that this is because he was worried about the backlash he would receive from those who preferred to stick to old and widespread beliefs. What we know for sure is that he was analysing his evidence and spending time doing other work alongside it. Before sharing his findings he wrote a book about the journey itself, called *The Voyage of the Beagle*. This left researchers and the public in anticipation of the news that was to come.**

**In 1859 *On the Origin of Species* was finally released: he was faced with a mixture of responses. From disbelief and dismissal to applause and amazement, it took the public time to get their heads around it. Eventually most people came to accept his discoveries, giving his theory its official name of Darwinism.**

**Darwin's published account of his five-year excursion flew from the shelves. His publisher took orders for 1,500 copies even before the book's release. The evidence that every living thing known to man could change over time was very desirable – even if the hefty book was filled with hard science. Darwin's work still remains popular today. Nearly two centuries on, who wouldn't want to hear firsthand from the father of evolution?**

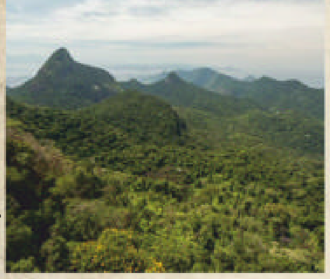
There are six editions of Darwin's iconic book

Source: Wiki/© Wellcome Collection

© Getty

# The GLOBAL TOUR

## Follow the journey of the Beagle as Darwin unfolded the history of life on Earth



© Getty

Darwin spent months in Rio de Janeiro studying insects

**April 1832** Rio de Janeiro, Brazil

### Rainforest questions

Previously Darwin's religion may have led him to see the good in Earth's creations. However, when he was in the rainforest he spent months observing its diverse creatures. One of the insects he documented were parasitic wasps. He noted the ugly side of nature as he observed them laying eggs in live caterpillars. When the eggs hatched, the young wasps would eat the caterpillar alive.

The large armadillo fossils Darwin found are now known to be part of the Glyptodon genus

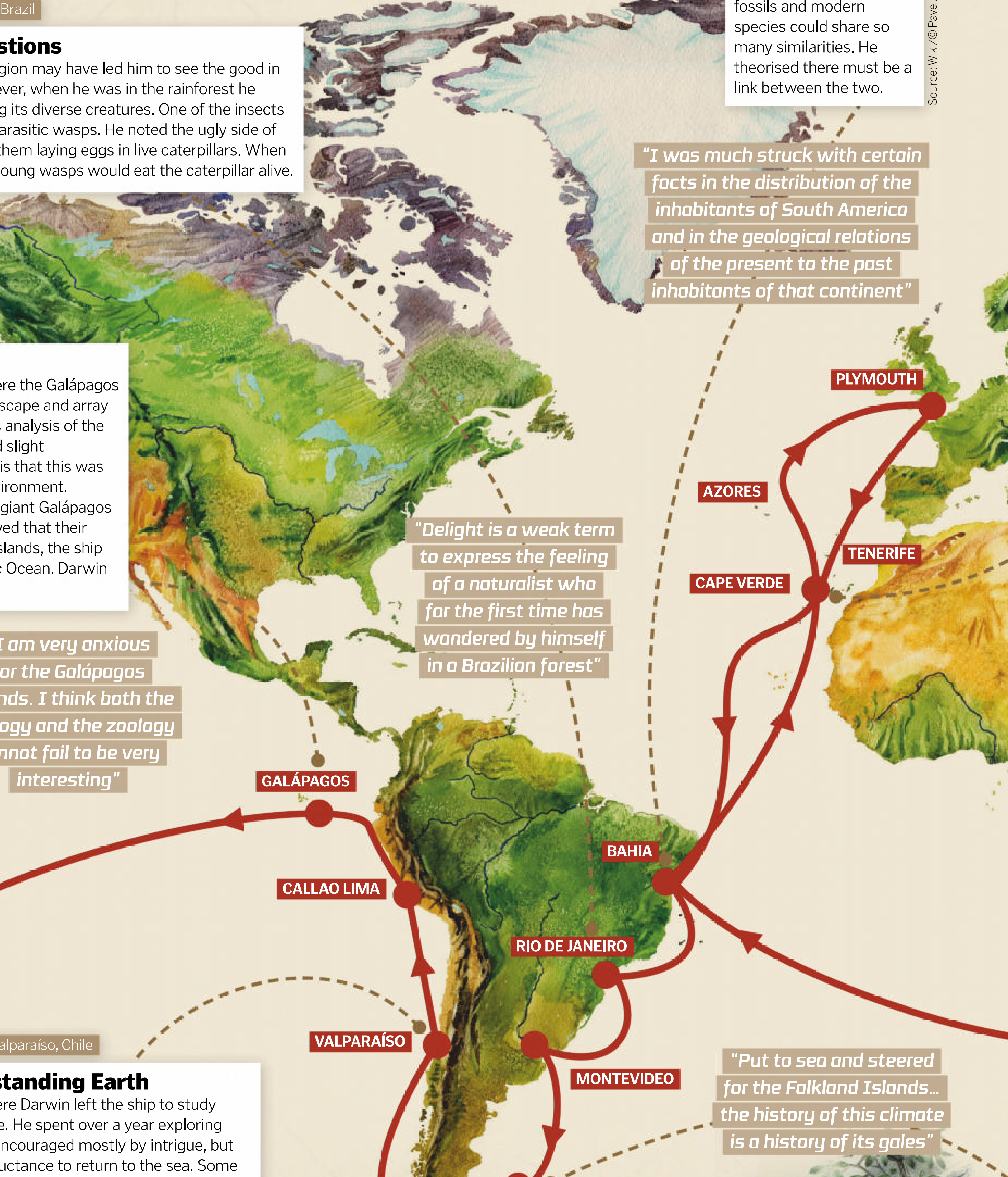
**February 1832** Bahia, Brazil

### Fossil finds

Here Darwin stumbled across the large shell fossil of an extinct armadillo and the bones of giant ground sloths. As he watched the living armadillos run around the floor, he wondered how fossils and modern species could share so many similarities. He theorised there must be a link between the two.

Source: Wiki /© Pavel Ríha,CB

*"I was much struck with certain facts in the distribution of the inhabitants of South America and in the geological relations of the present to the past inhabitants of that continent"*



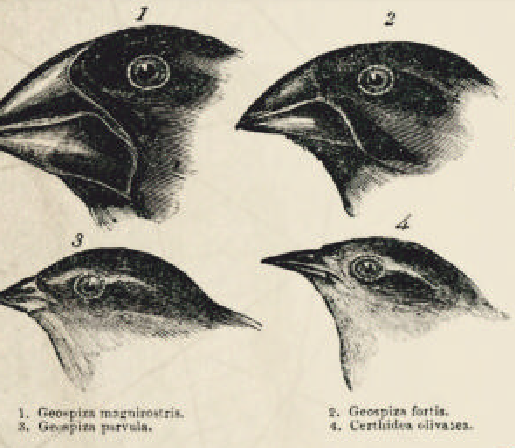
**September 1835** Galápagos Islands, Ecuador

### The famous finches

Darwin had high hopes for the group of islands that were the Galápagos – and he wasn't let down. He studied the volcanic landscape and array of plant life, but what became most significant was his analysis of the birds. As he travelled to the different islands he noticed slight differences in the finches. What he would later decide is that this was due to them evolving to live in each island's unique environment. Another animal that helped solidify his theory was the giant Galápagos tortoise. His close inspection and documentation showed that their shell structure differed by location. When leaving the islands, the ship had a lengthy journey to make across the South Pacific Ocean. Darwin used this time to make links between his specimens.

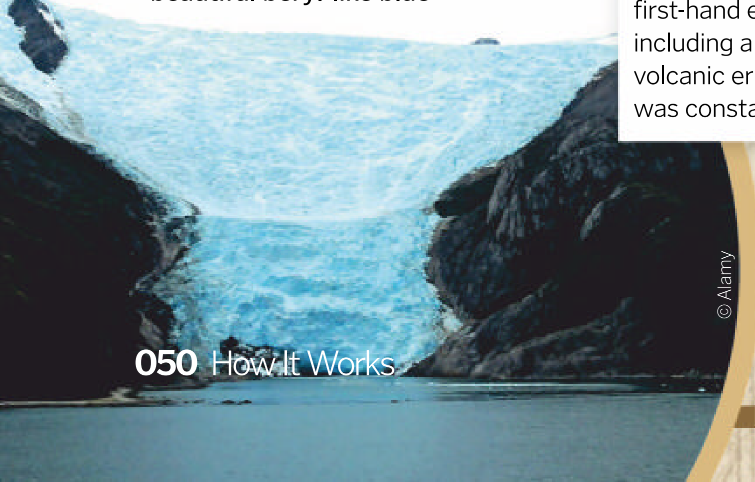
*"Delight is a weak term to express the feeling of a naturalist who for the first time has wandered by himself in a Brazilian forest"*

*"I am very anxious for the Galápagos Islands. I think both the geology and the zoology cannot fail to be very interesting"*


1
2
3
4
1. Geospiza magnirostris.
3. Geospiza parvula.
2. Geospiza fortis.
4. Certhidea olivasea.

The finches Darwin documented had beak shapes tailored to their diet

Darwin saw glaciers for the first time in Chile, describing them as 'beautiful beryl-like blue'



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**July 1834** Valparaíso, Chile

### Understanding Earth

This is where Darwin left the ship to study inland Chile. He spent over a year exploring this area, encouraged mostly by intrigue, but also his reluctance to return to the sea. Some of his most important experiences here were first-hand encounters of geological activity, including a huge earthquake, tsunami and volcanic eruption. He understood the planet was constantly shifting.

*"The world, the very emblem of all that is solid, moves beneath our feet like a crust over a fluid"*

*"Put to sea and steered for the Falkland Islands… the history of this climate is a history of its gales"*

Darwin was puzzled by the now-extinct Falkland Islands wolf as he didn't know what this large mammal was doing on the tiny islands

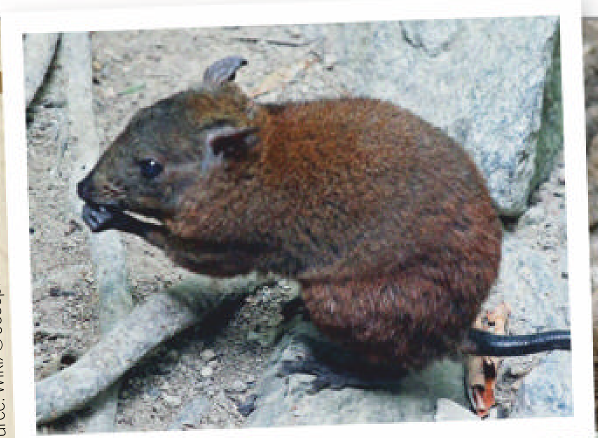
**DID YOU KNOW?** Over 120 species have been named after Darwin, such as darwinii and darwiniensis

**January 1832** St Jago, Cape Verde

## Written in the rocks

On his first stop Darwin began analysing the geology of the small Quail Island. He noticed a horizontal band of seashells in the rockface, far above the water. He believed the sea level must have dropped significantly. This was an early indication of how Earth continuously changes.

> "The geology of St Jago is very striking yet simple"



Source: Wiki/© Joseph C Boone

Darwin wrote that rat-kangaroos, found only in Australia, lived where rabbits usually would

Source: Wiki/© Nicolas Völcker

Darwin could tell which island the giant Galápagos tortoises were from just by observing their shells

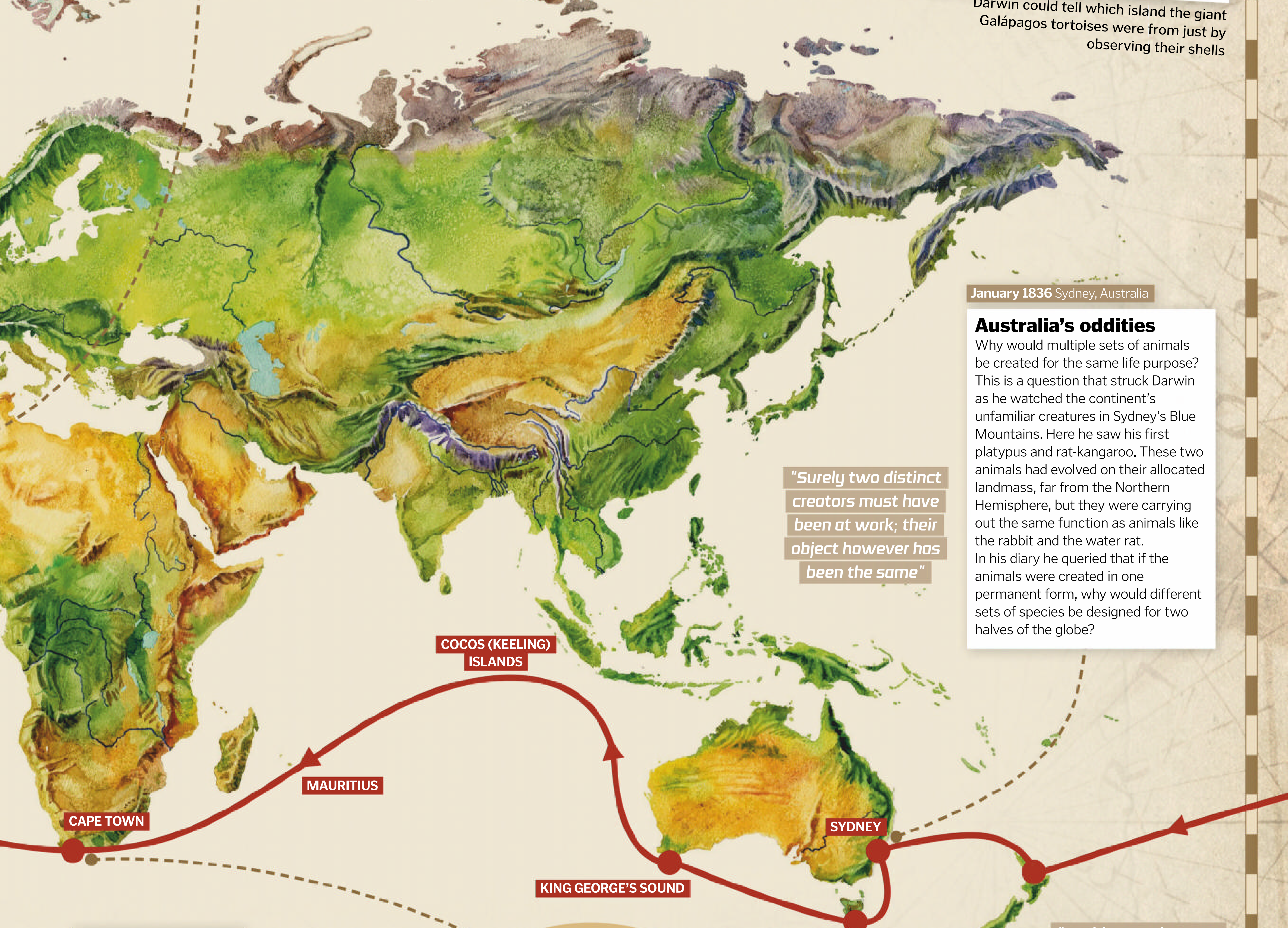
**January 1836** Sydney, Australia

## Australia's oddities

Why would multiple sets of animals be created for the same life purpose? This is a question that struck Darwin as he watched the continent's unfamiliar creatures in Sydney's Blue Mountains. Here he saw his first platypus and rat-kangaroo. These two animals had evolved on their allocated landmass, far from the Northern Hemisphere, but they were carrying out the same function as animals like the rabbit and the water rat.

In his diary he queried that if the animals were created in one permanent form, why would different sets of species be designed for two halves of the globe?

> "Surely two distinct creators must have been at work; their object however has been the same"



**March 1833** Falkland Islands

## Species survival

These islands were significant to Darwin making his evolutionary links. After his first visit, he returned a year later in 1834 for further study. Some of the invertebrates he had observed during his time there produced eggs in their thousands. Darwin noted that only a few of these were successful in surviving. These early signs would lead him to explain the process of natural selection.

Leaving Cape Town for England, Darwin began organising his notes, knowing that the hardest parts of his work would come at home

© Alamy

**June 1836** Cape Town, South Africa

## Quick stop

Despite it being a relatively short stop to prepare for the sail home, Darwin didn't put a halt to his research. In this area it was the rock formations that caught his interest. One of the arguments between geologists at the time was whether rocks such as granite were formed from molten rock or from seawater deposits. As Darwin surveyed the area, it became clear to him the rock was cooled, solidified magma.

> "Nothing can be more improving to a young naturalist than a journey in distant countries"

© Getty

© Getty

# EVEREST

## MISSION TO THE TOP OF THE WORD

**How was the race to the highest and one of the most dangerous peaks on Earth won?**

Words by **Ailsa Harvey**

Having met only weeks before, climbers Edmund Hillary and Tenzing Norgay shook hands before embracing each other in a moment that would entwine their names in history books forever. They were on top of the world – literally. After five hours of relentless climbing the duo made the first successful ascent to the top of Mount Everest, the highest peak on Earth. As the ultimate climbing goal for them both and the dream of most climbers, they had just 15 minutes to absorb the experience of being at 8,848 metres above sea level. Any longer and they may not have made it back to camp to tell the tale.

With this in mind, the pair spent some of their precious minutes searching the area for signs of those who had been before them. The bodies of two previous Everest hopefuls – Andrew Irvine and George Mallory of the 1924 attempt – were in the thoughts of Norgay and Hillary. However, they could find no sign of them having reached the summit.

Everest has been responsible for claiming over 300 lives and endangering many others, as it poses huge and unpredictable challenges. With high altitudes putting immense strain on human biology and with its icy terrain making each step a risk, when the climbers made it back to camp and the news spread, they were overwhelmed by global admiration and fame.

Norgay and Hillary were determined to be the first to conquer the world's highest mountain. They had done it. At the time they believed that the box had been ticked and no one else would put themselves through the danger to repeat their achievement. They couldn't have been more wrong. Today hundreds of people choose to follow in their footsteps every year. In stark contrast to the total isolation felt on the first successful expedition, during times of ideal weather conditions, queues form up to the mountain's summit. This creates dangerous standstills in the mountain's most deadly zones.

Whether you believe these adventurers to be brave, admirable or out of their minds, it is clear that Hillary and Norgay have provided knowledge and inspiration for many to find out how it feels to truly be on top of the world.

**DID YOU KNOW?** *Norgay left chocolate and biscuits on the summit as a food offering to Buddha*

Hillary quickly began to feel weak after taking his oxygen mask off at the summit

Hillary quickly began to feel weak after taking his oxygen mask off at the summit

© Alamy

> "Everest has claimed over 300 lives"

## Edmund Hillary

© Jamling Tenzing Norgay

Age at ascent **33**

Country **New Zealand**

Hillary's love for mountaineering arose when he was a high school student, leading him to big climbs such as Mount Ollivier in New Zealand. But what would take him from his local New Zealand Southern Alps to the greatest peak in the world was his post-war determination. After serving in World War II, Hillary joined an expedition headed for Everest's summit.

While reaching the summit of Everest was his most recognised achievement, Hillary went on to explore the South Pole and became one of the first people to climb Mount Herschel in 1967. If these accomplishments weren't enough, in 1985 Hillary flew in a plane with astronaut Neil Armstrong to the North Pole. With Everest often referred to as the 'third pole', this meant Hillary was the first to stand on all three.

As a tourist in the area that granted him fame, Hillary wanted to help the people of the Himalayas. He was responsible for creating the Himalayan Trust, building schools and hospitals in the Nepalese region. In 2003 he was given honorary citizenship of the country.

## Tenzing Norgay

© Jamling Tenzing Norgay

Age at ascent **39**

Country **Nepal**

Before the successful 1953 attempt, Norgay had attempted to top the mountain on several occasions. The first of these was in 1935. By 1952 Norgay was a record holder for the mountain, having reached 8,600 metres. With his experience holding more Everest expeditions than any other climber – and him being a local – it seemed appropriate to make him the Sherpa leader for the 1953 climb.

Having moved from Nepal to Darjeeling, India, Norgay became an instructor at the local mountain school. There he spent 20 years sharing his love of the mountains with the Indian students. Norgay was highly regarded as a hero among many people in both Nepal and India.

## Preparing for the ascent

**Much of the pair's preparation came from their previous escapades, building physically fit bodies and navigational professionalism. While Hillary used his experience on the many glacial mountains of New Zealand to his advantage, Norgay had six prior encounters with Everest already under his belt.**

**Turning their impressive combined climbing experience to the mission at hand, the three weeks leading up to the attempt involved intense training on the surrounding mountains. When the team were put into pairs for each attempt, Hillary and Norgay had shown great compatibility.**

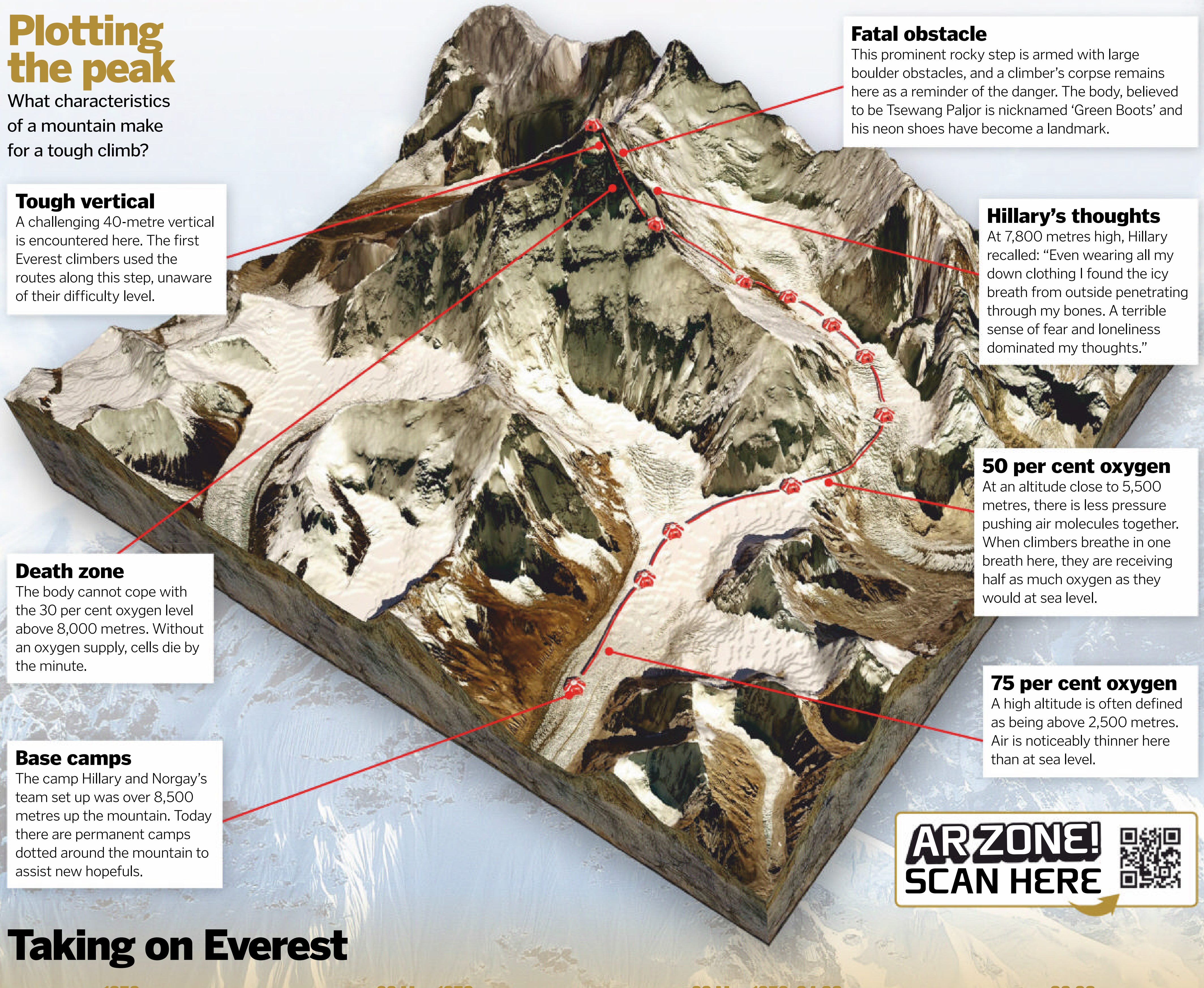
**During training together, they became familiar with the apparatus they would be using. Their choice was the open-circuit oxygen breathing apparatus. This involved carrying canisters of oxygen to inhale, while expelled air was released into the atmosphere through vents. Hillary and Norgay had to get used to climbing with this equipment on their backs.**

© Getty

The expedition group used Lhoste, another mountain over 8,000 metres, to train

## Plotting the peak

What characteristics of a mountain make for a tough climb?



### Fatal obstacle

This prominent rocky step is armed with large boulder obstacles, and a climber's corpse remains here as a reminder of the danger. The body, believed to be Tsewang Paljor is nicknamed 'Green Boots' and his neon shoes have become a landmark.

### Tough vertical

A challenging 40-metre vertical is encountered here. The first Everest climbers used the routes along this step, unaware of their difficulty level.

### Hillary's thoughts

At 7,800 metres high, Hillary recalled: "Even wearing all my down clothing I found the icy breath from outside penetrating through my bones. A terrible sense of fear and loneliness dominated my thoughts."

### 50 per cent oxygen

At an altitude close to 5,500 metres, there is less pressure pushing air molecules together. When climbers breathe in one breath here, they are receiving half as much oxygen as they would at sea level.

### Death zone

The body cannot cope with the 30 per cent oxygen level above 8,000 metres. Without an oxygen supply, cells die by the minute.

### 75 per cent oxygen

A high altitude is often defined as being above 2,500 metres. Air is noticeably thinner here than at sea level.

### Base camps

The camp Hillary and Norgay's team set up was over 8,500 metres up the mountain. Today there are permanent camps dotted around the mountain to assist new hopefuls.

© Illustration by Nicholas Forder

AR ZONE!
SCAN HERE

## Taking on Everest

### 1952

### Norgay comes close

As part of a Swiss expedition, Norgay and fellow climber Raymond Lambert come some 237 metres short of the summit, but have to return due to a lack of supplies.

### 26 May 1953

### Bourdillon and Evans' attempt

The first pair, Tom Bourdillon and Charles Evans, set off having been selected by the team leader, Sir John Hunt. 91 metres short of the summit, the weather turns, and oxygen tank issues and a fall force them back to camp.

### 29 May 1953, 04:00

### Hillary and Norgay prepare

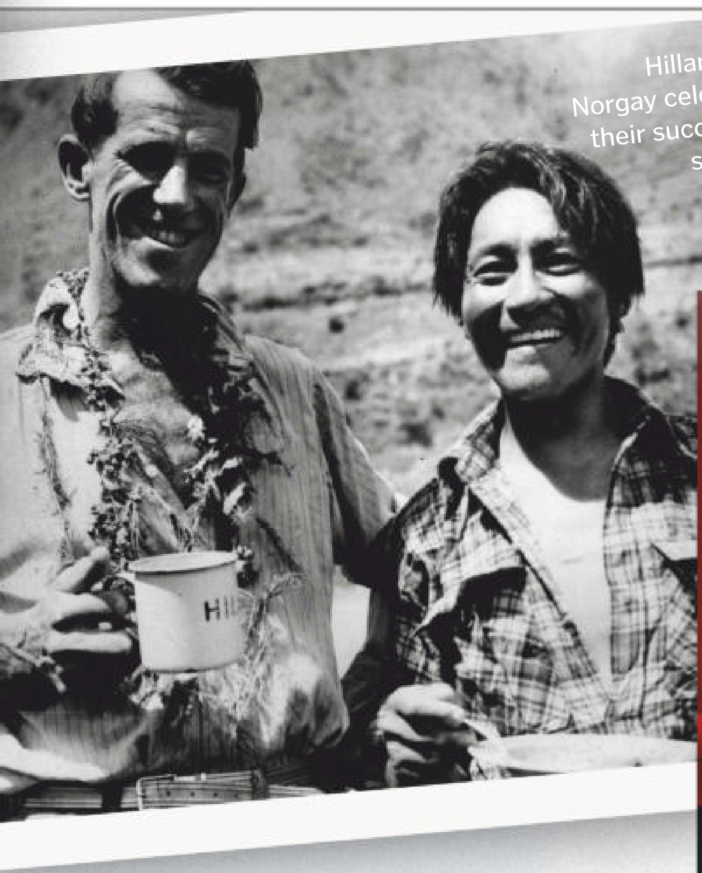
On the day of Hillary and Norgay's attempt they rise early to get ready, physically and mentally. Hillary wakes up to find his boots frozen solid and spends most of this time attempting to defrost them.

### 06:30

### Leaving camp

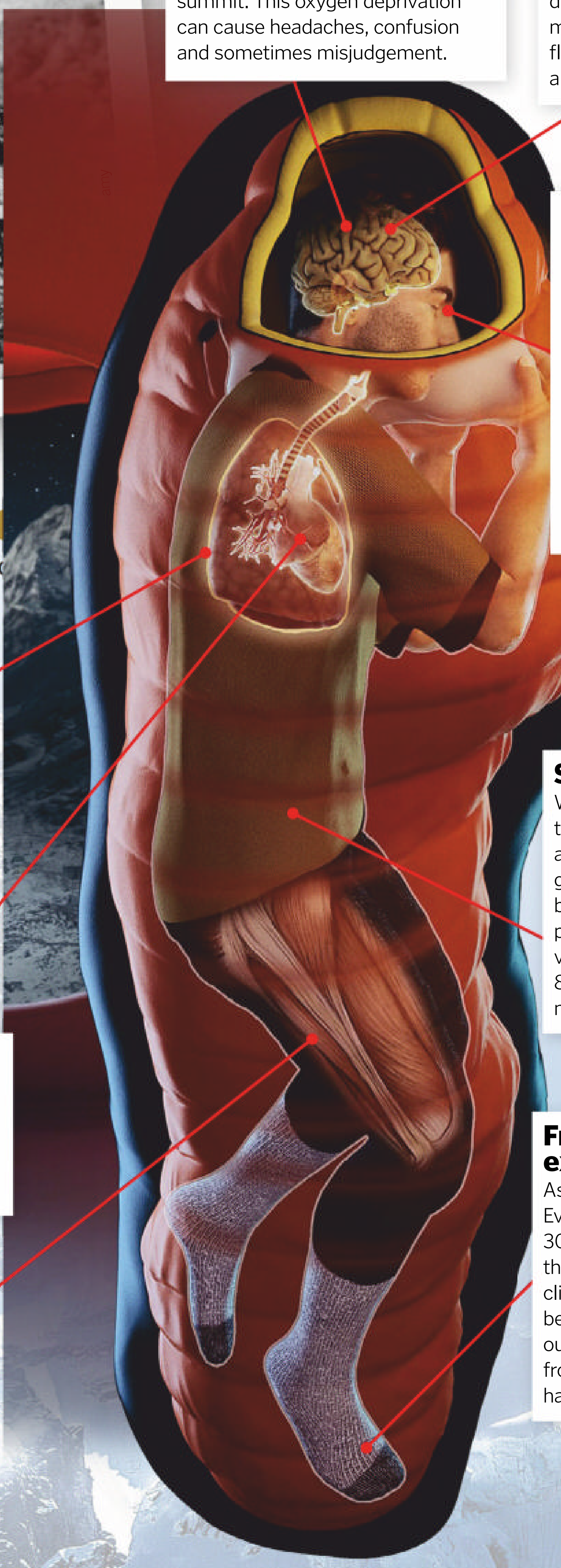
The duo leave their team at base camp and set off, determined to succeed. The expedition team hold high hopes for them as one of the strongest and most knowledgeable pairs.

**DID YOU KNOW?** *For years the pair refused to say who summited first, until Norgay revealed that it was Hillary in his book*


Hillary and Norgay celebrate their successful summit

# The body's battl

How are vital organs and tissue impacte by Everest's extreme climate?



### Brain function

At base camp there's 50 per cent less oxygen than at sea level, which drops 70 per cent less near the summit. This oxygen deprivation can cause headaches, confusion and sometimes misjudgement.

### Sleep deprivation

Sleep is essential for an effective climb the next day, but high altitudes make this difficult with fluctuating breathing rates and constant waking.

### Intense light

At the top of the mountain climbers enter the upper troposphere layer of Earth's atmosphere, where levels of ultraviolet radiation are 29-times higher and much more damaging. Climbers need to cover exposed skin, including the eyes, to limit damage.

### Breathing difficulties

At altitudes just before the 3,000-metre mark, the lungs can swell. Blood is being directed to parts of the lungs with the most oxygen. In other areas blood vessels are narrowing. At the summit breathing rates become up to six-times faster to try and maximise air inhaled.

### Racing heart

As the main organ providing the entire body with essential oxygen, it has to work much harder at high altitudes. On Everest it may feel like your heart is jumping out of your chest even when the body is resting.

### Muscle waste

In a combination of metabolic changes and dehydration, climbers spending long periods at high altitudes often find their muscles wasting away as they become malnourished.

### Slow digestion

With blood being diverted to more critical organs and climbing muscles, the gut's oxygen supply becomes less of a priority. Nausea and vomiting occur in over 80 percent of the mountain's climbers.

### Frozen extremities

As temperatures on Everest can drop to minus 30 degrees Celsius during the climbing season, climbers' bodies may begin to freeze from the outside in. The process of frostbite starts at the hands, feet and face.

© Illustration by Nicholas Forder

## 5 FACTS ABOUT

### ELEMENTS FOR SUCCESS

1 **Courage** Well aware of the mountain's high fatality record, Hillary and Norgay proceeded, conquering the deadly Khumbu Icefall. This is regarded as the most dangerous part of the mountain, with ice constantly falling.

2 **Passion** Both climbers were no strangers to mountain exploration, and they showed that to achieve such a feat, you need to really want to do it. Being paired together in training, their determination rubbed off on each other and carried them right to the peak.

3 **Urgency** When are you ready to battle the elements of Everest? In 1952 Britain heard of France being given permission to attempt the climb, and it knew it had to act fast to be first. This element of competition gave Hillary and Norgay more to work for.

4 **Lessons** While they were the first to succeed, Hillary and Norgay weren't the first to try. They were able to take note of failing oxygen levels, risky areas, timing and required equipment to better prepare for the task ahead.

5 **Conditions** Setting their attempt in May was a wise decision, as the wind on the mountain tends to die down in the months of May and September. September would not be as safe, as fresh snow tends to fall, increasing the likelihood of killer avalanches.

> *"They had just 15 minutes to absorb the experience of being at 8,848 metres"*

**AR ZONE! SCAN HERE**

### 09:00
### South Summit

Two-and-a-half hours into the climb, Norgay and Hillary successfully reach the second highest peak on Earth – the South Summit.

### 10:00
### The Hillary Step

Coming across a 12-metre-high rocky step in the mountain and without the knowledge of its existence, they're unprepared to navigate it. Hillary wedges himself in a crack in the rock and pulls himself up. From there he is able to hold a rope for Norgay.

### 11:30 to 11:45
### 15 minutes on top of the world

Only at 15 metres from the summit does Hillary truly believe they will make it. They spend their short time at the top in a state of disbelief and joy. Here they take photographs to commemorate it.

### June 1953
### Announcement

A message is sent to Queen Elizabeth II as soon as they return to base camp. She receives this message in June and the world is informed the next day.

# Super-stealthy scout helicopter

## How the S-97 Raider's skilful steering and targeted precision flies circles around its competitors

Words by **Ailsa Harvey**

Most helicopters can be heard approaching overhead as their rotor blades hum a warning. They often cruise over in a flat line, sticking to higher paths in the sky. If this were to happen during a top-secret military mission, it would make the craft an easy target and its cover would be instantly blown. To be stealth-capable, each aspect of standard helicopter technology needs to be fine-tuned, taking tight manoeuvrability, sneakily silent flight and unerring precision to the extreme.

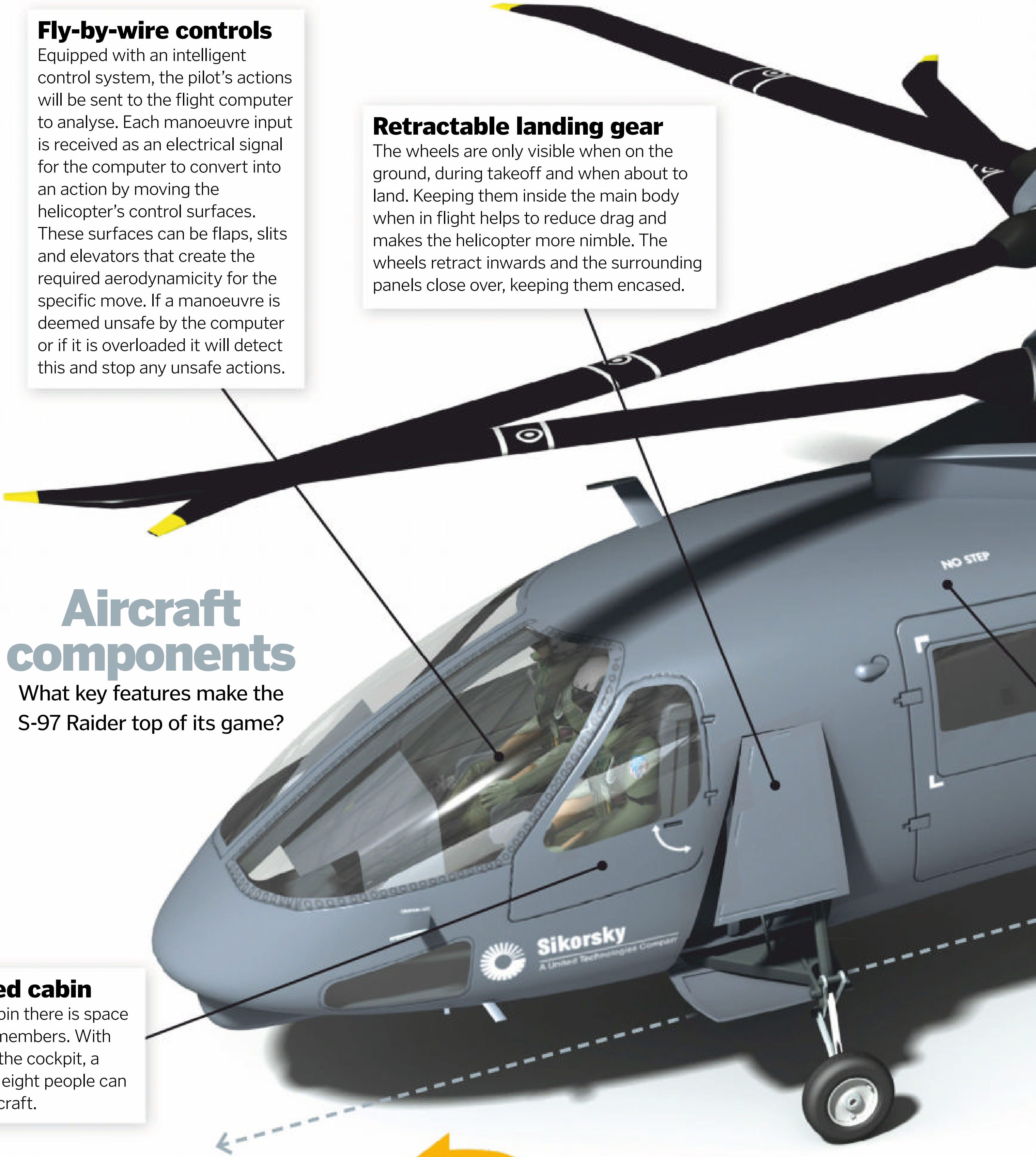
The S-97 Raider, manufactured by Sikorsky, does just this. Aiming to exceed the abilities of other existing helicopters, the S-97 was designed to be untouchable. Its steering capabilities allow it to dodge, whirl and climb the sky at rapid speeds. While these manoeuvres are exhilarating just to observe, they are also deemed critical in combat for the likes of the US army. Confidently following close to the ground – adjusting altitude to match an obstacle-stricken landscape to near perfection – the technology helps to protect and support the troops inside while on crucial scouting missions.

Scout and attack helicopters are light and agile for battlefield applications

© Lockheed Martin

## Aircraft components

What key features make the S-97 Raider top of its game?



**Fly-by-wire controls**
Equipped with an intelligent control system, the pilot's actions will be sent to the flight computer to analyse. Each manoeuvre input is received as an electrical signal for the computer to convert into an action by moving the helicopter's control surfaces. These surfaces can be flaps, slits and elevators that create the required aerodynamicity for the specific move. If a manoeuvre is deemed unsafe by the computer or if it is overloaded it will detect this and stop any unsafe actions.

**Retractable landing gear**
The wheels are only visible when on the ground, during takeoff and when about to land. Keeping them inside the main body when in flight helps to reduce drag and makes the helicopter more nimble. The wheels retract inwards and the surrounding panels close over, keeping them encased.

**Six seated cabin**
Inside the cabin there is space for six crew members. With two pilots in the cockpit, a maximum of eight people can board the aircraft.

## Top technical manoeuvres

Explore the aircraft's mission-critical aerobatics

### PRECISE LOW-SPEED HANDLING

The Raider can perform its sharp turns and tight manoeuvres without having to reach high speeds first. This enables the aircraft to dodge and move more freely when closer to the ground.

### LEVEL ACCELERATION

With the ability to increase power without changing flying height, the helicopter is equipped for speedy flights when confined to one height.

### SHARPER TURNING

Compared to its competitors, the S-97 Raider can turn around in just half the distance that it would take in other helicopters. This means that if there was a threat and the aircraft needed to turn around, it could do so quicker for a faster getaway.

### HIGH-SPEED CRUISING

Time can be everything in a mission, and the Raider has mechanisms in place to move across battlefields in less time. It shifts power between the propellor and the rotor, reducing exposure time to threats.

© Lockheed Martin

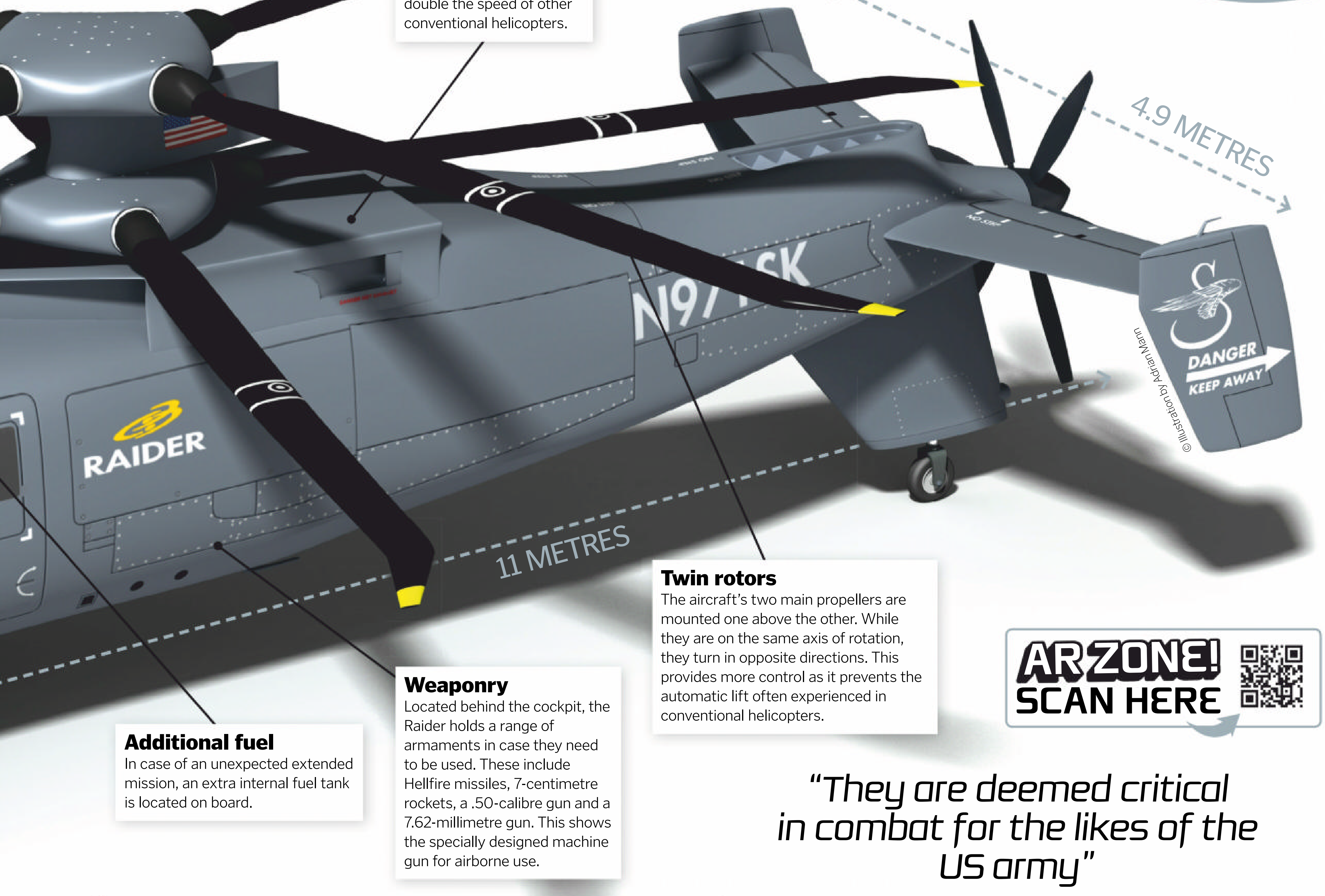
**DID YOU KNOW?** *The S-97 Raider's carbon footprint is 15 per cent less than a conventional helicopter's*

## Ensuring safety

**The S-97 Raider takes pride in its safety, but it hasn't always been smooth flying. In 2017 the helicopter's experimental flight resulted in a crash landing that saw the first S-97 prototype ripped to pieces. Sikorsky put the problem down to a software glitch, which has since been revisited. When the crash occurred in 2017, the two main propellers collided. This double-rotor design helps the helicopter reach record-breaking speeds, and it was concerning that this could be the main safety issue. However, due to it being identified as a software error, the crash is believed to have happened irrespective of the unique design, and the helicopter continues to grace the skies.**

The two sets of propellers are perfectly aligned

© Lockheed Martin



© Illustration by Adrian Mann

**Single engine**
The helicopter is powered by one engine, generating speeds of over 400 kilometres an hour. This is double the speed of other conventional helicopters.

**Twin rotors**
The aircraft's two main propellers are mounted one above the other. While they are on the same axis of rotation, they turn in opposite directions. This provides more control as it prevents the automatic lift often experienced in conventional helicopters.

**Additional fuel**
In case of an unexpected extended mission, an extra internal fuel tank is located on board.

**Weaponry**
Located behind the cockpit, the Raider holds a range of armaments in case they need to be used. These include Hellfire missiles, 7-centimetre rockets, a .50-calibre gun and a 7.62-millimetre gun. This shows the specially designed machine gun for airborne use.

AR ZONE!
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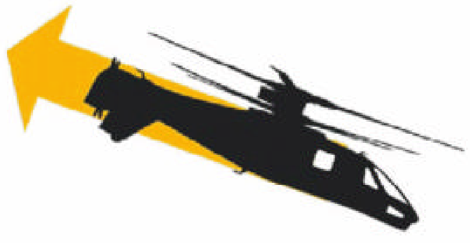
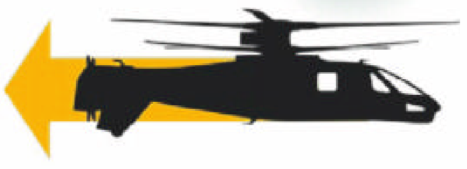
*"They are deemed critical in combat for the likes of the US army"*



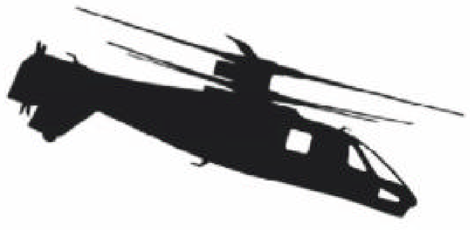
### TARGETED DIVE

Putting the propeller in reverse thrust acts against the aircraft's forward movement. This allows for a slow and controlled dive downwards.



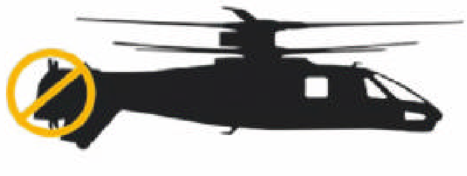
### LEVEL DECELERATION

Using a similar deceleration method as in the dive, this simple manoeuvre turns the angle of the propeller blades, reversing thrust and slowing down movement. This helps keep accurate focus on any targets.



### DOWNWARD HOVER

Pointing the nose down, pilots can keep still in this position. They can also do the same facing upwards. This becomes useful when aiming a sensor towards a target in irregular terrain such as mountains.



### PROPELLER DISENGAGEMENT

The pilot has control over when the tail propeller is on and off. While most helicopters need this running at all times, the Raider can shut it down, enabling it to limit noise and approach targets without being detected.

AR ZONE!

# Cone-laying vehicles

## How these clever machines are taking over one of the roles of road workers

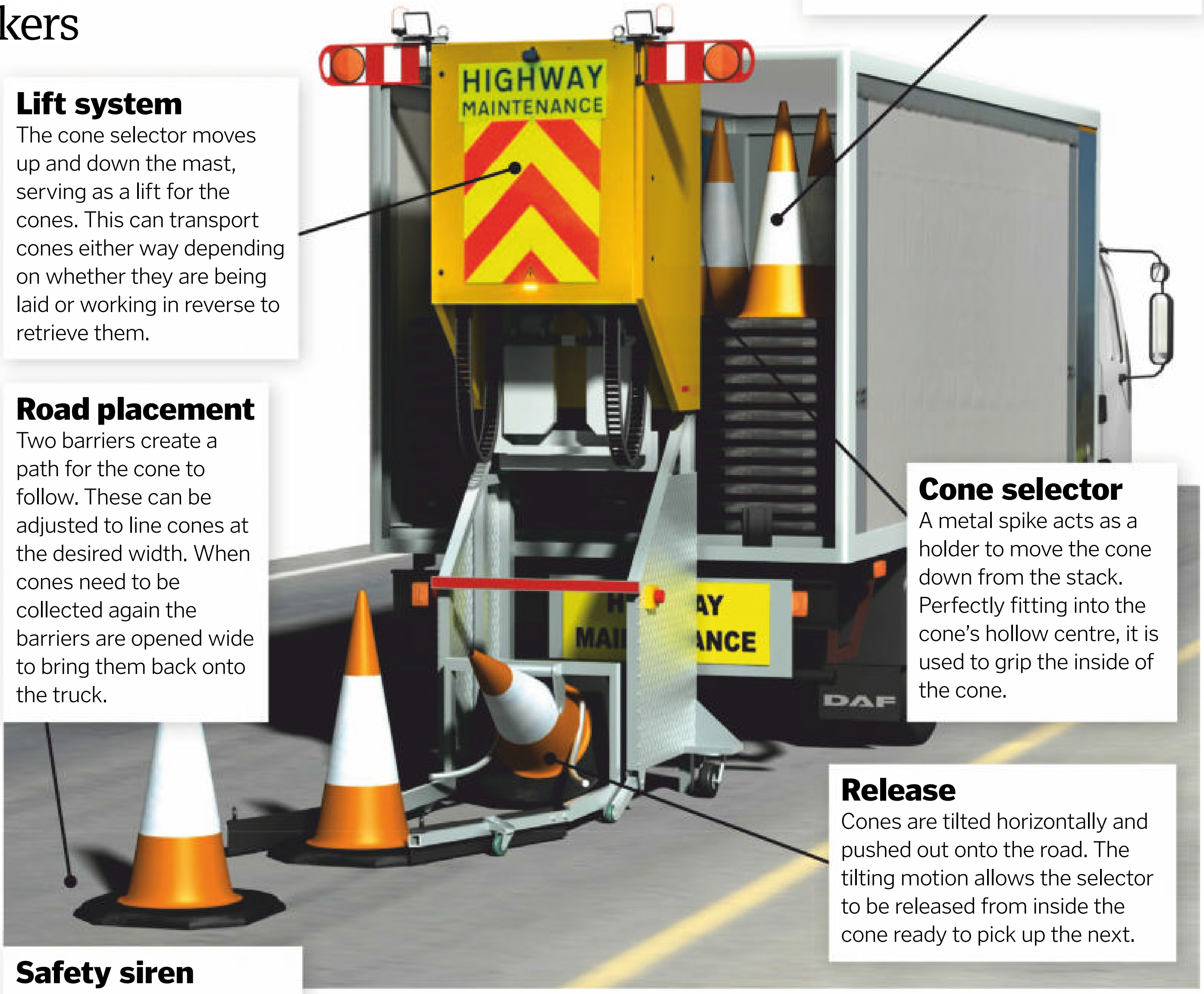
Despite most being neon orange in colour, cones are so common on today's roads that you may pass them by without taking much notice of their presence. Traffic cones are a simple invention but help to safely redirect cars away from roadworks and warn drivers of hazards in advance.

You often see them lining major roads and motorways, but how often do you see them being laid? This job is usually undertaken at night or during periods of lighter traffic. During cone laying two road workers usually hang out of the back of a slow-moving truck, rhythmically taking it in turns to place them down. Timing this well means that cones are evenly spaced. Although done at quieter times, there are usually still some cars on the roads at the same time, so this job can be a laborious and dangerous one. As cones are only temporarily placed, this job is soon repeated to collect them all back.

Now highways in the UK are testing robotic cone-laying systems. Robotic cone layers are capable of carrying out precise, repeated actions as the vehicle is driven, with cones being both laid and collected efficiently. This saves hundreds of hours of work and allows highway workers to continue with other duties.

© Getty

Traffic cones can be used on motorways to block entire lanes



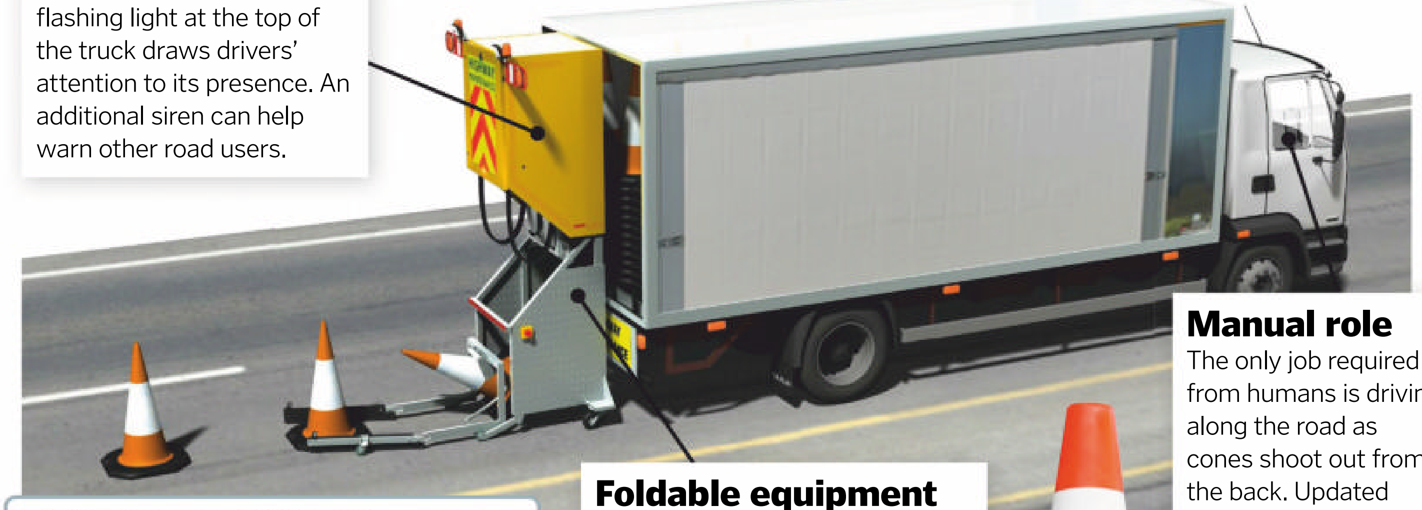
**Cone stacks**
Before laying the cones are stacked up tall and lined up in position. Because the cone grabber follows the same sequence, the cone stacks are lowered with each selection to ensure there is a cone in place to be targeted.

**Lift system**
The cone selector moves up and down the mast, serving as a lift for the cones. This can transport cones either way depending on whether they are being laid or working in reverse to retrieve them.

**Road placement**
Two barriers create a path for the cone to follow. These can be adjusted to line cones at the desired width. When cones need to be collected again the barriers are opened wide to bring them back onto the truck.

**Cone selector**
A metal spike acts as a holder to move the cone down from the stack. Perfectly fitting into the cone's hollow centre, it is used to grip the inside of the cone.

**Release**
Cones are tilted horizontally and pushed out onto the road. The tilting motion allows the selector to be released from inside the cone ready to pick up the next.



**Safety siren**
With cones being laid alongside ongoing traffic, a flashing light at the top of the truck draws drivers' attention to its presence. An additional siren can help warn other road users.

**Foldable equipment**
When travelling between sites the cone-distributing system can be folded away. This makes it more compact when not in use.

**Manual role**
The only job required from humans is driving along the road as cones shoot out from the back. Updated autonomous vehicles are planned for the future, but for now manually driven trucks are the safest option.

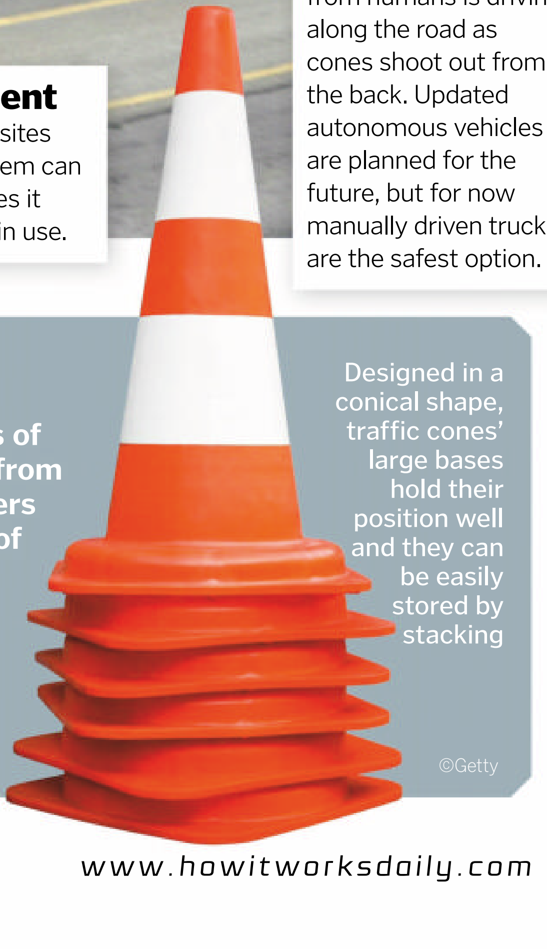
© Illustration by Adrian Mann

AR ZONE! SCAN HERE

## Cones through history

**Before traffic cones, large wooden barriers were used to section off parts of the road. These were both difficult to move and install onto roads, as well as causing extra damage to cars involved in accidents. Early versions of traffic cones were made of wood or concrete. These were much easier to lay, but these materials continued to make them an extra hazard for cars during collisions.**

**First patented in 1943, the invention of the traffic cone is credited to Charles Scanlon, who designed a hollow 'safety marker' by sewing together pieces of tyres. As a painter he wanted to keep cars away from fresh paint. From there the conical-shaped markers increased in popularity and found a wider range of functions. From roads and sports fields to car parks and side streets, today they have transformed into the plastic cones we are all familiar with and have made their way all over the world. Reflective surfaces were added in 1971, making them more visibile to drivers.**



Designed in a conical shape, traffic cones' large bases hold their position well and they can be easily stored by stacking

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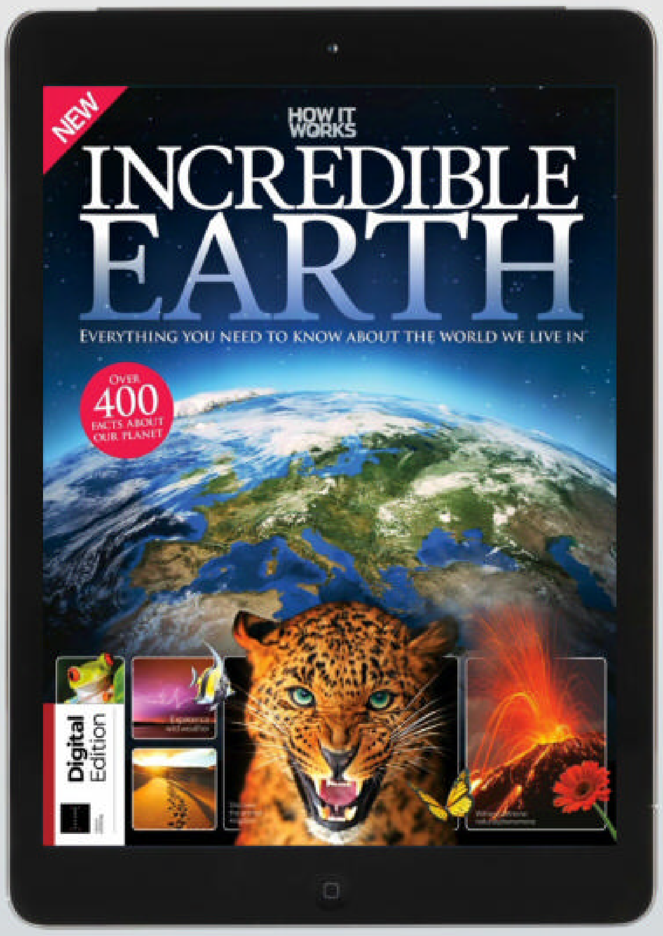
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# 10 SECRETS OF SPACE

Our universe is full of odd phenomena – and we don't have all the answers. Here we look at the science of the most intriguing

Answering questions and solving puzzles has been the driving force behind astronomy for thousands of years, even if it often seems that for every mystery solved, a new one springs up. Today astronomers like to think they have a fairly good understanding of the way our universe works, including processes from the life cycle of stars to the evolution of galaxies, and it's certainly true that we know a lot more than we did a century ago. But there are still plenty of loose ends, and new ones are emerging all the time.

Some of these mysteries are discoveries that may seem at first to break our already established rules. Of course, we can't be sure until these particular enigmas are resolved, but often finding solutions to puzzles like this is just a matter of time; once a strange mystery object such as the 'impossible star' SDSS J102915+172927 or the rectangular galaxy LEDA 074886 is announced to the world, scientists can turn their collective efforts and a huge array of observational techniques to learning more about it and understanding why it defies convention.

Others require a little more patience – for instance, new images of Uranus' satellite Miranda would certainly reveal more about its turbulent history, but we're sadly unlikely to be sending another probe that way any time soon. The long-standing mysteries of the Sun's corona have had to await the development of new techniques for studying it and new spacecraft, and the ins and outs of 'dark matter', which permeates the entire cosmos, still remain frustratingly elusive.

Perhaps the most exciting mysteries of all are those that come completely out of the blue, such as dark energy accelerating the expansion of the universe. Three decades ago astronomers didn't even know there was a puzzle to be solved, yet now dark energy is one of the hottest topics in the field. It's discoveries like this that will doubtless be discovered in the future that help drive forward our understanding of not just space, but also our place within it.

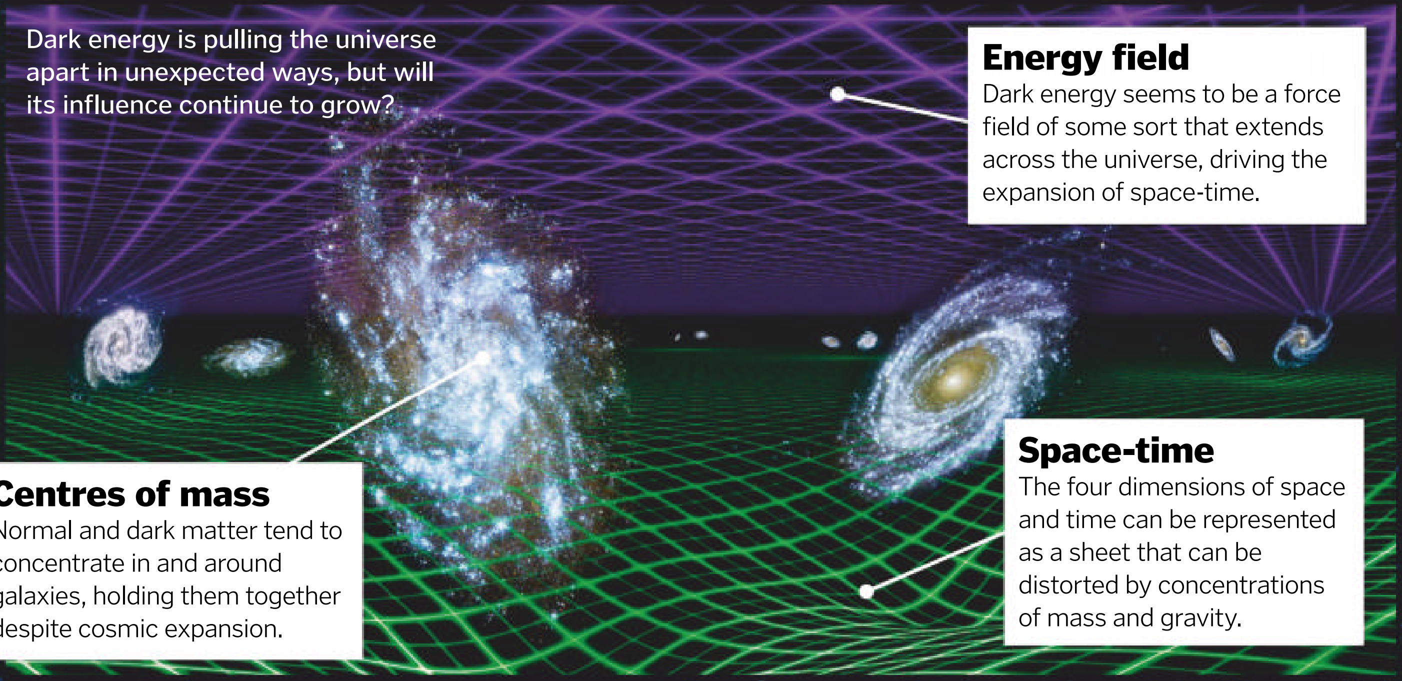
**DID YOU KNOW?** *NASA's GRAIL satellite explained variations in the Moon's gravity via mapping, caused by asteroid impacts*

## 1 Most of the universe is missing

Astronomers have been getting to grips with a mystery that has undermined a lot of what we previously thought we knew about the cosmos. We once thought the universe was dominated by two substances: normal, or 'baryonic', matter – matter that interacts with light and other forms of radiation – and invisible 'dark' matter that is transparent to light and only makes its presence felt through gravity.

But in the late 1990s cosmologists found an unexpected twist: the expansion of the universe, which should be slowing down due to the gravitational drag of the matter within it, is speeding up. The evidence for this comes from distant supernovae explosions in galaxies billions of light years from Earth, which appear fainter than we would expect if we relied on previous models of cosmic expansion.

The phenomenon responsible is called 'dark energy' and seems to account for a staggering 70 per cent of the universe. Nobody knows exactly what dark energy is, but perhaps the most intriguing – and even alarming – aspect to the discovery is that it seems to be increasing. Until around 7.5 billion years ago, expansion was slowing; then the strength of dark energy overcame gravity and the expansion picked up again. If the growth of dark energy continues, some predict that the universe might end in a 'Big Rip' many billions of years from now when dark energy becomes so powerful that galaxies, stars and even individual particles of matter are torn apart.



Dark energy is pulling the universe apart in unexpected ways, but will its influence continue to grow?

**Energy field**
Dark energy seems to be a force field of some sort that extends across the universe, driving the expansion of space-time.

**Centres of mass**
Normal and dark matter tend to concentrate in and around galaxies, holding them together despite cosmic expansion.

**Space-time**
The four dimensions of space and time can be represented as a sheet that can be distorted by concentrations of mass and gravity.

## 2 The origin of cosmic rays

Cosmic rays are high-speed, high-energy particles from space which we usually detect via the less energetic particles they produce as they enter Earth's upper atmosphere. Astronomers divide them into several classes depending on their speed and energy, and most seem to originate from distant supernovae. Perhaps the most troublesome, however, are the ultra-high-energy rays – tiny subatomic particles that can carry the same amount of energy as a baseball travelling at 100 kilometres per hour.

For some years the likeliest origin for ultra-high-energy particles seemed to be gamma-ray bursts (GRBs) – enormous blasts of energy linked to dying stars or merging black holes. But studies using the IceCube Neutrino Observatory, a particle detector buried beneath Antarctica, failed to find the predicted neutrino particles that would be linked to this origin. So if GRBs aren't the source of the highest energy rays, what is? Astronomers are revisiting the idea that they are formed by natural particle accelerators around supermassive black holes in the heart of distant active galaxies.

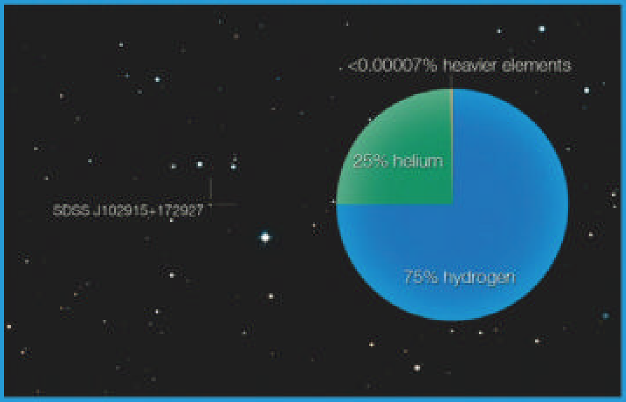
If exploding stars or colliding black holes can't create high-energy cosmic rays, astronomers need to find something even more powerful…

## 3 Impossible stars

In 2011 scientists at the European Southern Observatory made a strange discovery in the form of SDSS J102915+172927, or Caffau's Star – a star roughly 4,500 light years from Earth in the constellation of Leo. This star has about four-fifths the mass of our Sun and is composed almost entirely of hydrogen and helium, the two lightest elements in the universe. Together they make up around 99.99993 per cent of its entire composition, with heavier elements – known as metals – almost entirely absent.

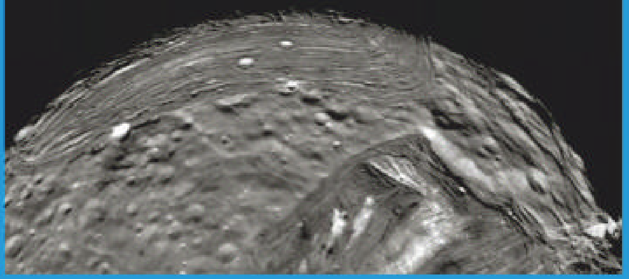
Such a pure lightweight star must have formed more than 13 billion years ago from the raw cosmic materials remaining after the Big Bang, but the problem is that according to accepted models of star formation it should never have been born.

In order to produce enough gravity to collapse and form a star, astronomers think that a protostellar cloud needs to have either a significant amount of heavier metals or a larger overall mass – small, low-density stars like this one simply shouldn't exist.

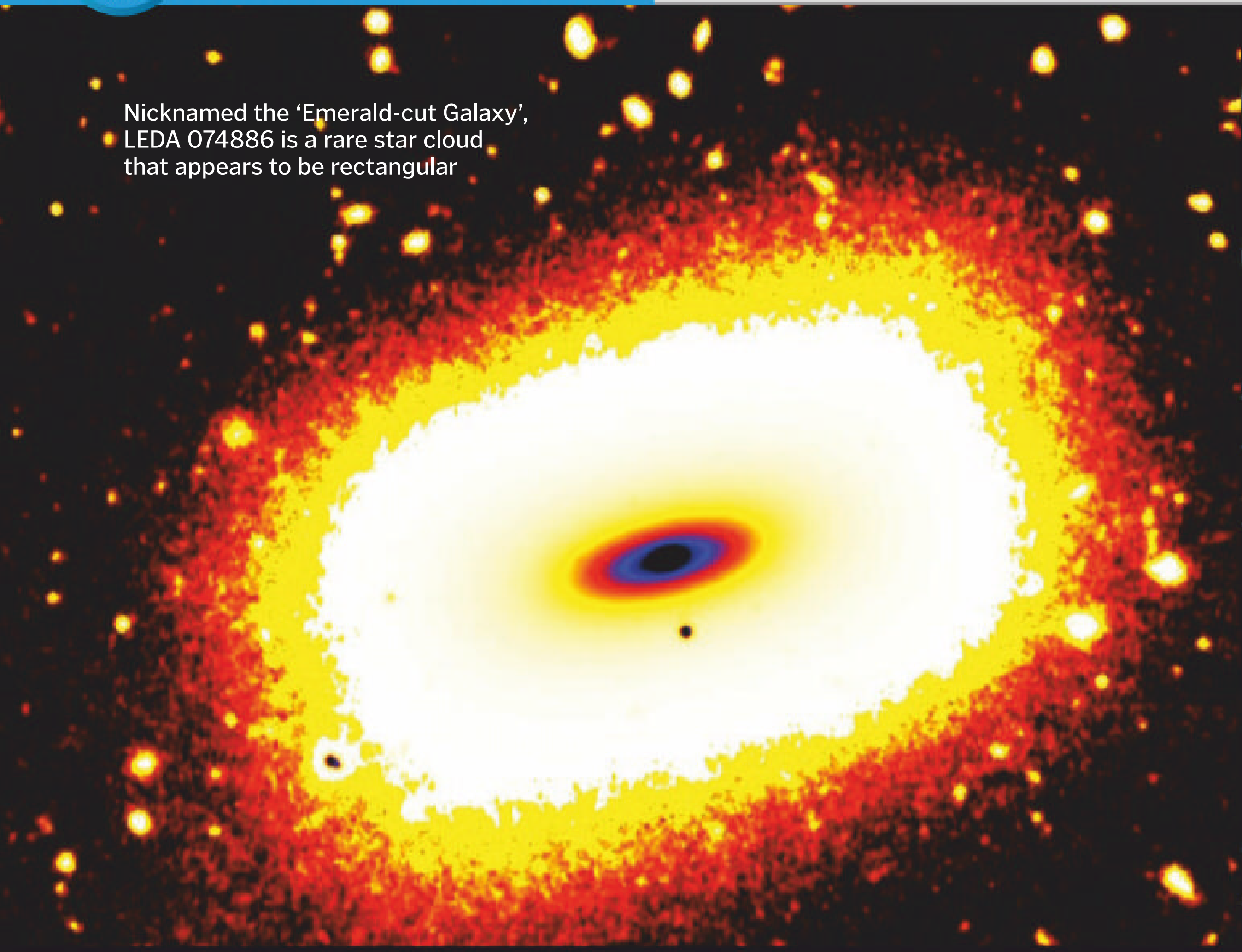


## 4 Miranda mystery

When Voyager 2 flew past Uranus in 1986, its close-up views of the planet's inner satellite Miranda surprised everyone. This small moon shows a huge variety of different surface features that seem to break the rule that smaller worlds don't show geological activity. Astronomers soon nicknamed it the 'Frankenstein moon' since it looks like it has been broken up and reassembled, perhaps in some ancient interplanetary impact. But there's a problem with this theory: Miranda orbits so close to Uranus that if it had broken up completely, it could not have pulled itself together again. Instead some scientists now think it was pulled around and reshaped by extreme tides.



Miranda's patchwork appearance is evidence of a turbulent past, but did it really break apart and reform?



Nicknamed the 'Emerald-cut Galaxy', LEDA 074886 is a rare star cloud that appears to be rectangular

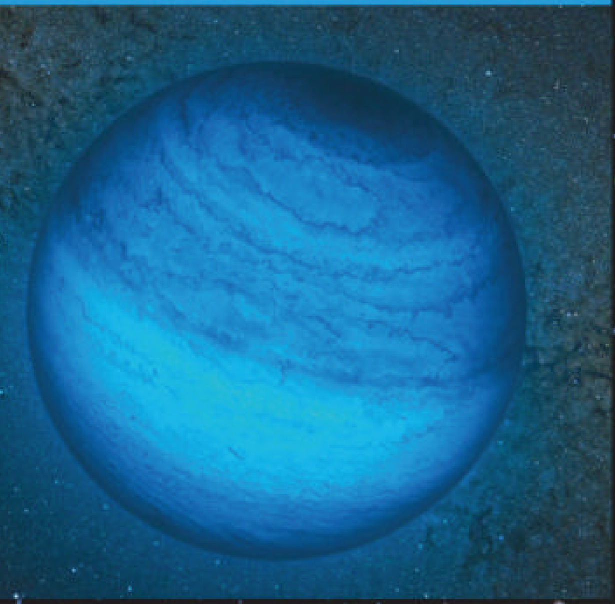
## 5 Rectangular galaxies

The laws of orbital mechanics mean that stars always follow elliptical orbits under the influence of gravity, so in large groups they form either flattened disc-like spirals or ball-shaped ellipticals. The sharp corners of a rectangle should be impossible, but nevertheless astronomers have found several galaxies with apparently rectangular features. For example, LEDA 074886 in the constellation of Eridanus is a compact, rectangular galaxy embedded in a nearby galaxy cluster. The big question is whether its shape is a long-lived structure or brief coincidence – astronomers who have studied it with the giant Japanese Subaru telescope think the latter is more likely and that a collision and merger between two galaxies could have scattered the outlying stars into their current box-like distribution, triggering a wave of star formation at the new centre.

## 6 The rogue planet

**According to the standard definition, a planet is a substantial object in orbit around a star, formed from the debris left behind in the aftermath of starbirth. So how do some planets end up floating alone through space, far from any stars? Astronomers have discovered several of these, of which the closest and most intriguing goes by the catalogue name of CFBDSIR J214947.2-040308.9.**

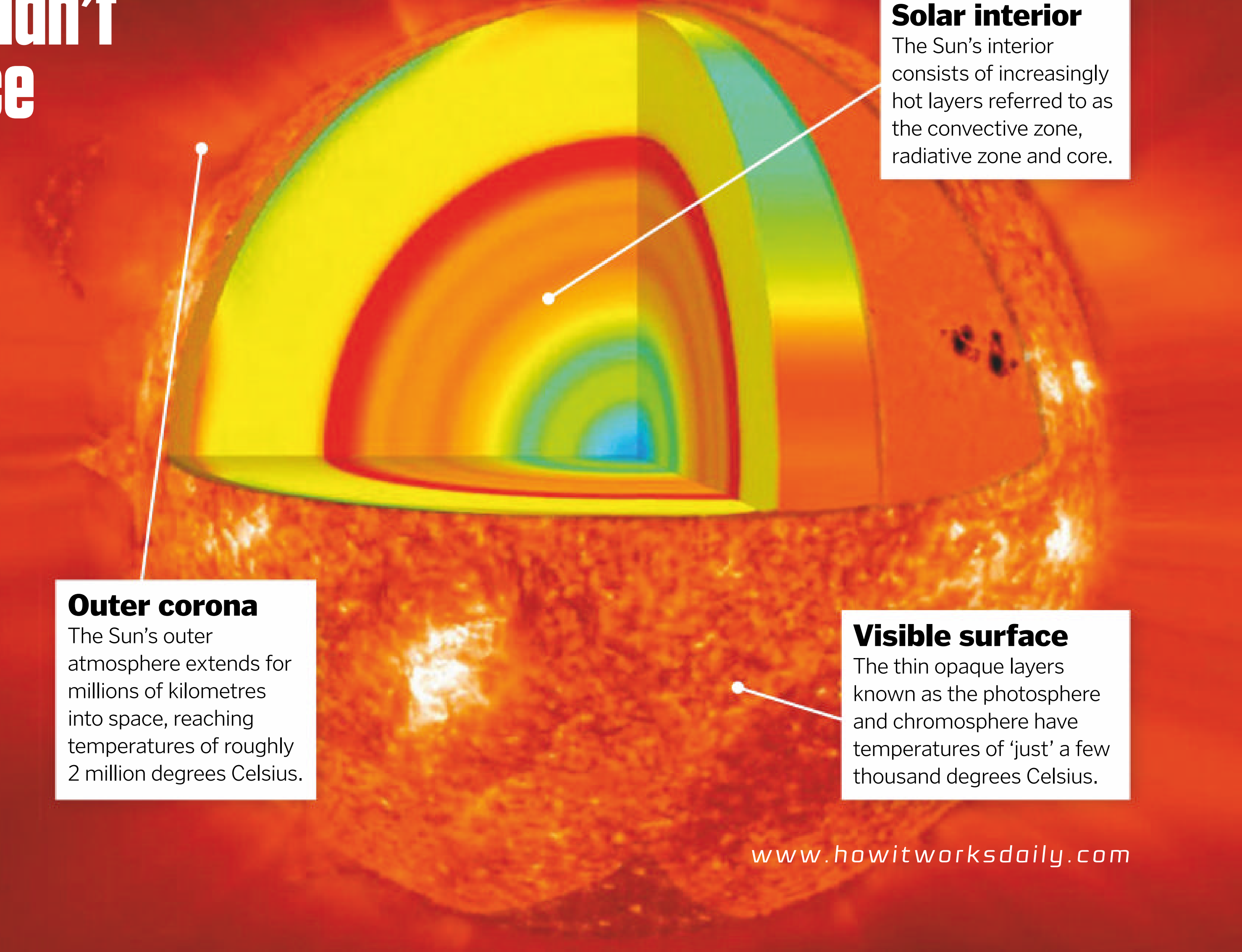
**First spotted in 2012, this rogue planet sits about 100 light years away in the AB Doradus moving group – a cluster of young stars. With a surface temperature of around 400 degrees Celsius, it is probably a gas giant much heavier than Jupiter either still warm from the events of its formation or perhaps with its own internal energy source driven by gravitational contraction. Too far from any star to shine by using reflected light, the planet was only detected thanks to the infrared glow from its surface. As with all rogue planets, astronomers aren't sure if it started life in orbit around a star before being flung off into space – perhaps in a close encounter with another star – or if it formed independently from the same nebula as the surrounding cluster, in which case it is not a planet but a 'sub-brown dwarf star'.**



Floating in the midst of the AB Doradus cluster, this rogue world gives astronomers a rare look at a planet far from any stars

## 7 The Sun's corona shouldn't be hotter than its surface

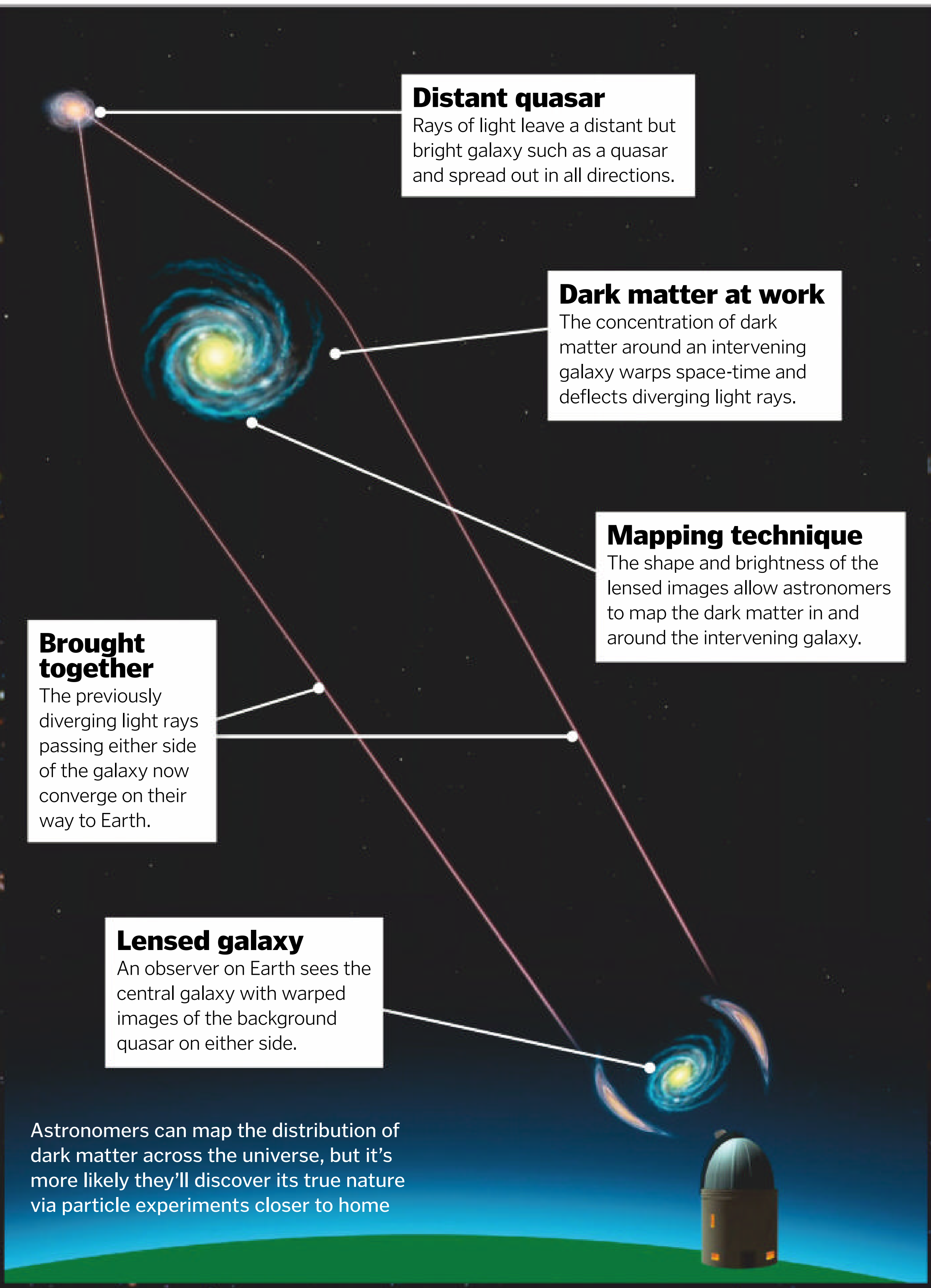
**The Sun's visible surface is one of its coolest regions, with an average temperature of around 5,500 degrees Celsius. While it's no surprise that temperatures towards the core rise to around 15 million degrees Celsius, the fact that the Sun's thin outer atmosphere, the corona, only visible from Earth during an eclipse, rapidly soars to around 2 million degrees Celsius is more puzzling. This huge rise in temperature takes place across a 'transition region' about 100 kilometres thick, and solar physicists still aren't sure what drives it. The leading contenders are shocks caused by sound waves rippling across the surface and 'nanoflares' – bursts of energy released by changes to the Sun's magnetic field. Imaging technology carried aboard NASA's Solar Dynamics Observatory mission is helping to map both of these phenomena in unprecedented detail, and may soon provide some definitive answers to this enigma. The Parker Solar Probe launched in 2018 will also look to inspect the corona.**



**Solar interior**
The Sun's interior consists of increasingly hot layers referred to as the convective zone, radiative zone and core.

**Outer corona**
The Sun's outer atmosphere extends for millions of kilometres into space, reaching temperatures of roughly 2 million degrees Celsius.

**Visible surface**
The thin opaque layers known as the photosphere and chromosphere have temperatures of 'just' a few thousand degrees Celsius.



**Distant quasar**
Rays of light leave a distant but bright galaxy such as a quasar and spread out in all directions.

**Dark matter at work**
The concentration of dark matter around an intervening galaxy warps space-time and deflects diverging light rays.

**Mapping technique**
The shape and brightness of the lensed images allow astronomers to map the dark matter in and around the intervening galaxy.

**Brought together**
The previously diverging light rays passing either side of the galaxy now converge on their way to Earth.

**Lensed galaxy**
An observer on Earth sees the central galaxy with warped images of the background quasar on either side.

Astronomers can map the distribution of dark matter across the universe, but it's more likely they'll discover its true nature via particle experiments closer to home

## 8 The quest to find dark matter

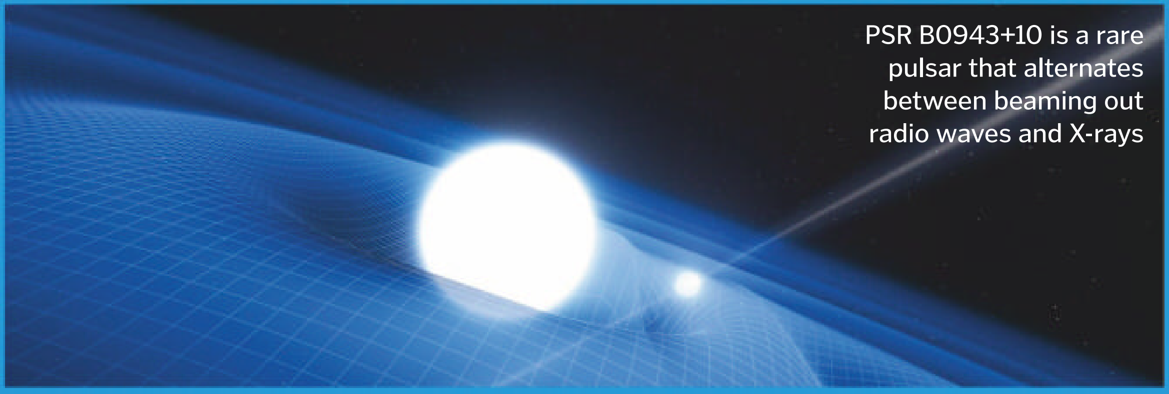
Since the 1930s astronomers have understood that there's a lot more to the universe than just the material we can see. Normal – or baryonic – matter can't help but interact with light and other forms of electromagnetic radiation – stars emit visible light, hot gas emits X-rays and even the coldest material in the universe emits radio waves and infrared, and clouds made up of this type of matter also absorb radiation that passes through them. But there's another class of matter that ignores light completely – so-called 'dark matter' that is not just dark but entirely transparent to all types of radiation. It gives itself away only through its gravitational influence on visible objects around it – for example, affecting the orbits of stars within galaxies and galaxies within galaxy clusters. More recently astronomers have also developed techniques to map the distribution of dark matter through 'gravitational lensing' – the way in which large concentrations of matter deflect the passage of nearby light waves.

Evidence suggests that dark matter outweighs visible matter by roughly six to one. But what is it made of? Astronomers used to think that 'massive compact halo objects', or MACHOs – normal matter in forms too dark and faint to detect, such as lone planets and black holes – might make a contribution, but as our telescopes have improved, it's become clear that these objects don't exist in sufficient quantities. Instead cosmologists now believe dark matter consists largely of 'weakly interacting massive particles', or WIMPs – exotic subatomic particles that don't interact with radiation or normal matter, but possess considerable mass. But what exactly WIMPs are is still to be worked out.

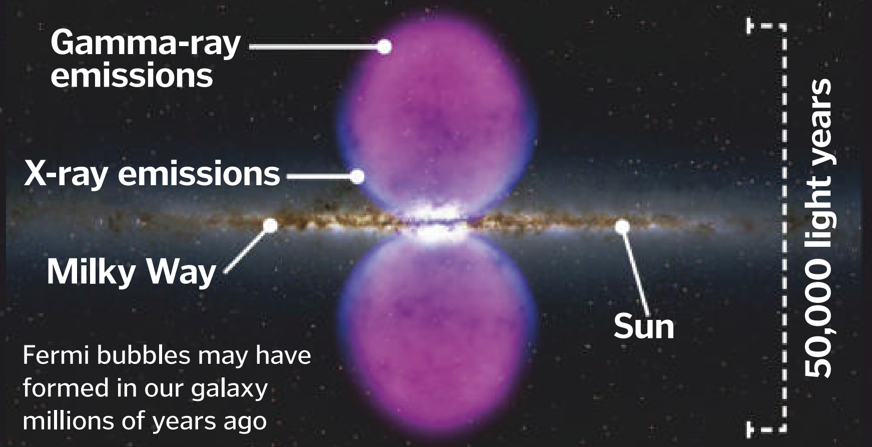
## 9 Unpredictable pulsars

Pulsars are supposed to be the most reliable timekeepers in the universe. These collapsed neutron stars – the super-dense cores of once-massive stars that long ago went supernova – channel intense beams of radiation into space along their powerful magnetic fields, creating a 'cosmic lighthouse' that appears to switch on and off many times each second from our point of view on Earth. Most pulsars emit either X-rays or radio waves – or both – but in early 2013 astronomers discovered a unique pulsar known as PSR B0943+10. This pulsar emits beams alternately at radio and X-ray wavelengths, changing from one type of radiation to the other in just a few seconds.

It could be that this behaviour is linked to the 'starquakes' on the neutron star's surface, which astronomers believe can also cause glitches when a pulsar's period changes speed, or it could be that something strange is going on.



PSR B0943+10 is a rare pulsar that alternates between beaming out radio waves and X-rays



Fermi bubbles may have formed in our galaxy millions of years ago

## 10 Galactic bubbles

Two bubbles of superhot gas extend above and below our Milky Way. Found in 2010 via the Fermi Gamma-ray Space Telescope, the 'Fermi bubbles' are some of the largest structures in our part of the universe, but how did they form? The bubbles have sharp outer edges and are hollow on the inside, suggesting they are expanding from an origin in a single event, perhaps millions of years ago. One theory is that they are the remnants of shock waves generated when the centre of our galaxy went through a huge burst of star formation followed by a wave of supernovae. The other is that they were ejected during activity from our galaxy's normally dormant central supermassive black hole.

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# Launch pad at sea

Currently floating in a Russian dockyard is a massive mobile platform for launching satellites – but how does it work?

The Odyssey sea launch platform is a satellite launch complex that was situated in the Pacific Ocean, before being brought into dock. It has three segments: the Rocket segment, the Marine segment and the Home Port segment.

On land, the Home Port segment provides a facility for preparing and fuelling the satellite payload. It also serves as a base to provide support to the marine components of the complex.

Out at sea the complex has two vessels. The first is a ship known as the Sea Launch Commander – a mobile rocket-assembly unit where satellites are loaded onto the carrier rocket and transported to the launch platform.

The platform itself is a converted North Sea drilling rig. It is self-propelled and semi-submersible, allowing the position, angle and stability of the platform to be carefully calibrated for each individual satellite launch.

Satellites are sent into space using a Zenit-3SL rocket, under the guidance of an automated ground control system. The platform is evacuated for the launch, which can either be controlled using the Sea Launch Commander ship – which retreats to a safe distance of five kilometres – or from its home port.

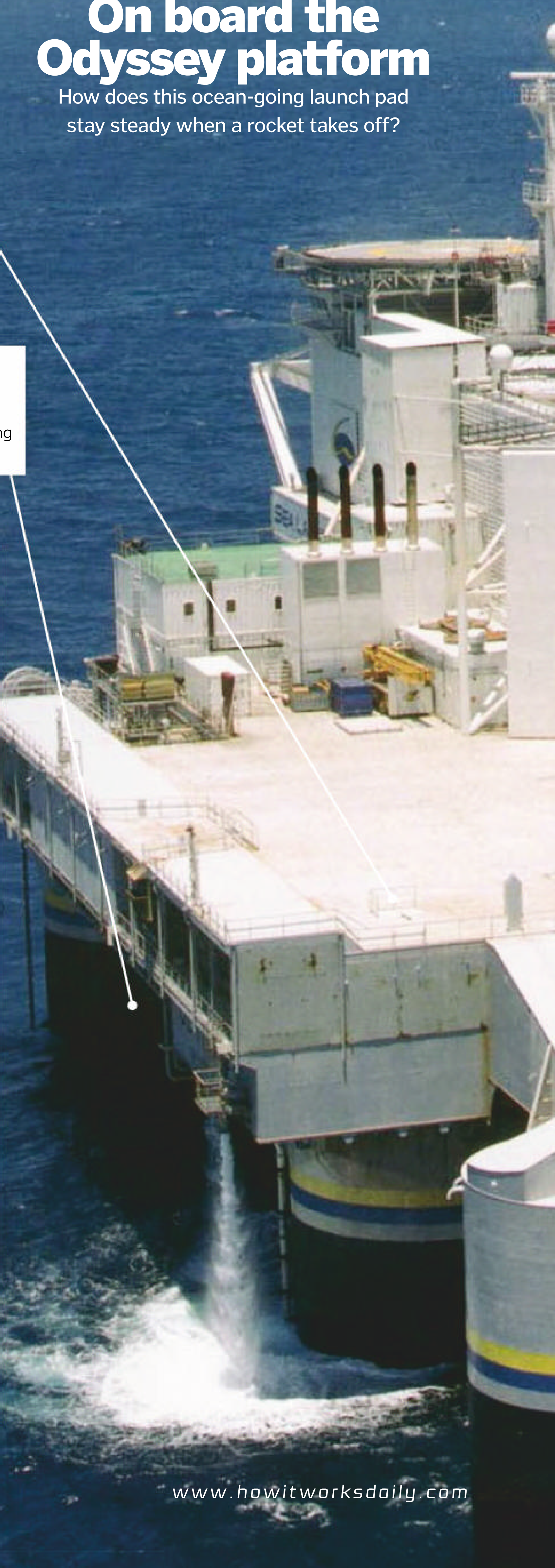
The launch platform was anchored at the equator, where the rotational speed of Earth is at its greatest. This provides an extra boost to the launch vehicle and enables rockets to be sent to a geostationary orbit without having to correct for launch latitude. In contrast, the same rocket taking off from Cape Canaveral Air Force Base in Florida at 28.5 degrees north would have to weigh significantly less to reach geostationary orbit.

The remote ocean location of the Odyssey platform also minimises any interference from overhead air traffic and provides additional safety over facilities that are nearer to populated areas on land.

> *"The launch platform was anchored at the equator, where the rotational speed of Earth is at its greatest"*

## On board the Odyssey platform

How does this ocean-going launch pad stay steady when a rocket takes off?



**Converted oil rig**
At 67 metres wide and 133 metres long, the platform is one of the largest semi-submersible self-propelled vessels on the planet.

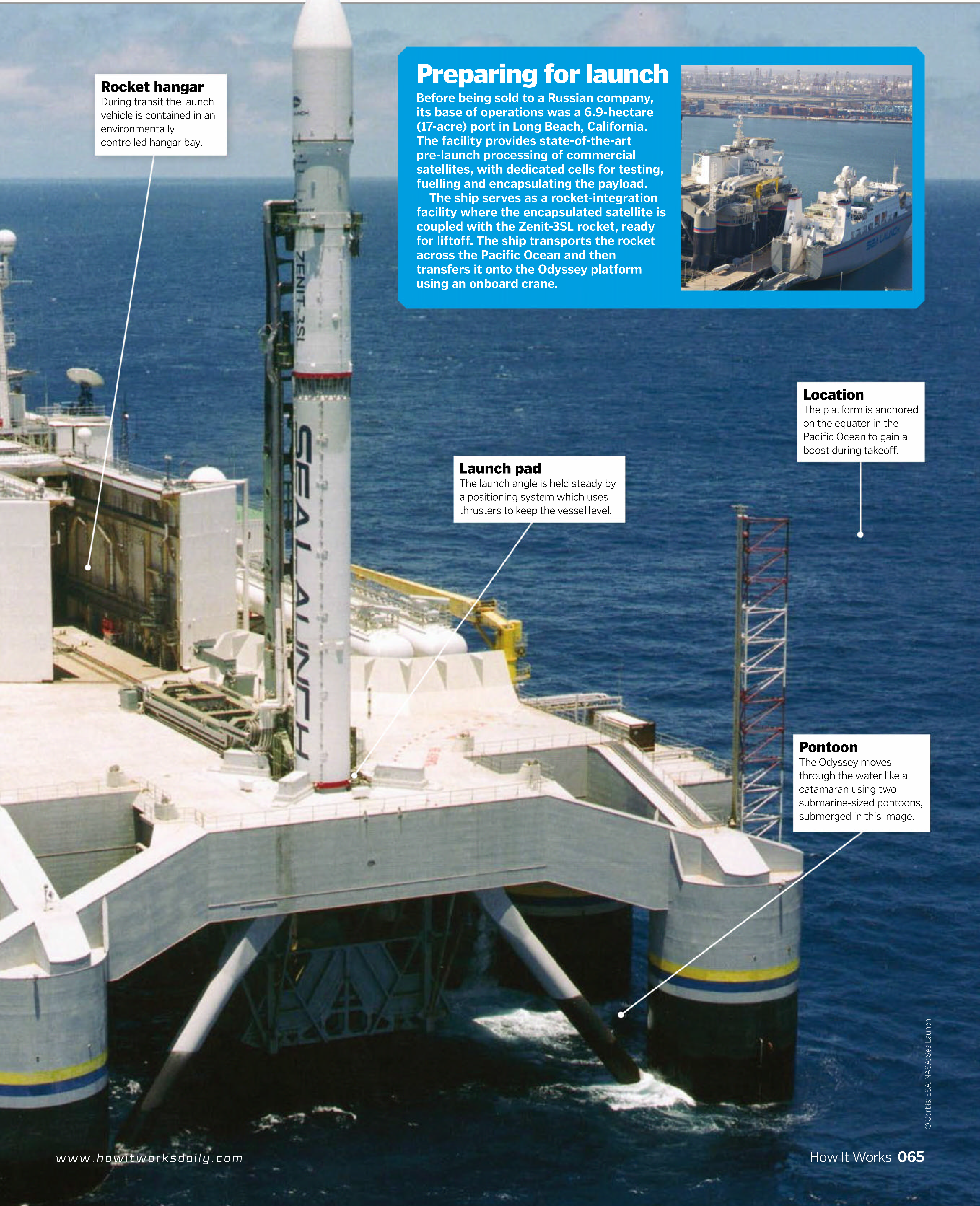
**Ballast pumps**
Pumps within the pontoons enable the platform to partially submerge, stabilising the vessel before a launch.

### Zenit-3SL up close

Satellites are launched from the platform on single-use Zenit-3SL carrier rockets. The custom-designed rockets are powered by a liquid-oxygen/kerosene engine and are designed to accurately carry the satellite payload to a geosynchronous orbit around Earth.

Once in the launch position and fully fuelled, a three-day automated countdown is started and all personnel are evacuated from the platform. To date 36 rockets have launched; three of these failed, and a further rocket placed its payload in the wrong orbit.

In 2007 a foreign object in the engine of one rocket during launch led to the entire platform being engulfed in a massive fireball. The automated countdown ensured that there were no casualties, but the failure caused extensive damage to the Odyssey that took months to repair.



**Rocket hangar**
During transit the launch vehicle is contained in an environmentally controlled hangar bay.

**Launch pad**
The launch angle is held steady by a positioning system which uses thrusters to keep the vessel level.

**Location**
The platform is anchored on the equator in the Pacific Ocean to gain a boost during takeoff.

**Pontoon**
The Odyssey moves through the water like a catamaran using two submarine-sized pontoons, submerged in this image.

## Preparing for launch

**Before being sold to a Russian company, its base of operations was a 6.9-hectare (17-acre) port in Long Beach, California. The facility provides state-of-the-art pre-launch processing of commercial satellites, with dedicated cells for testing, fuelling and encapsulating the payload.**

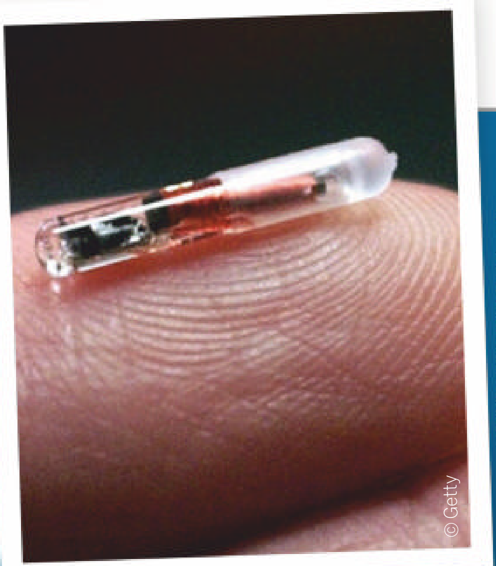
**The ship serves as a rocket-integration facility where the encapsulated satellite is coupled with the Zenit-3SL rocket, ready for liftoff. The ship transports the rocket across the Pacific Ocean and then transfers it onto the Odyssey platform using an onboard crane.**

© Corbis; ESA; NASA; Sea Launch

# Implanting identity chips

Could these tiny internal mini-computers be the new frontier in contactless identification?

Words by **Scott Dutfield**



© Getty

Near-field communication chips have become a way for biohackers to have a biologically built-in ID card

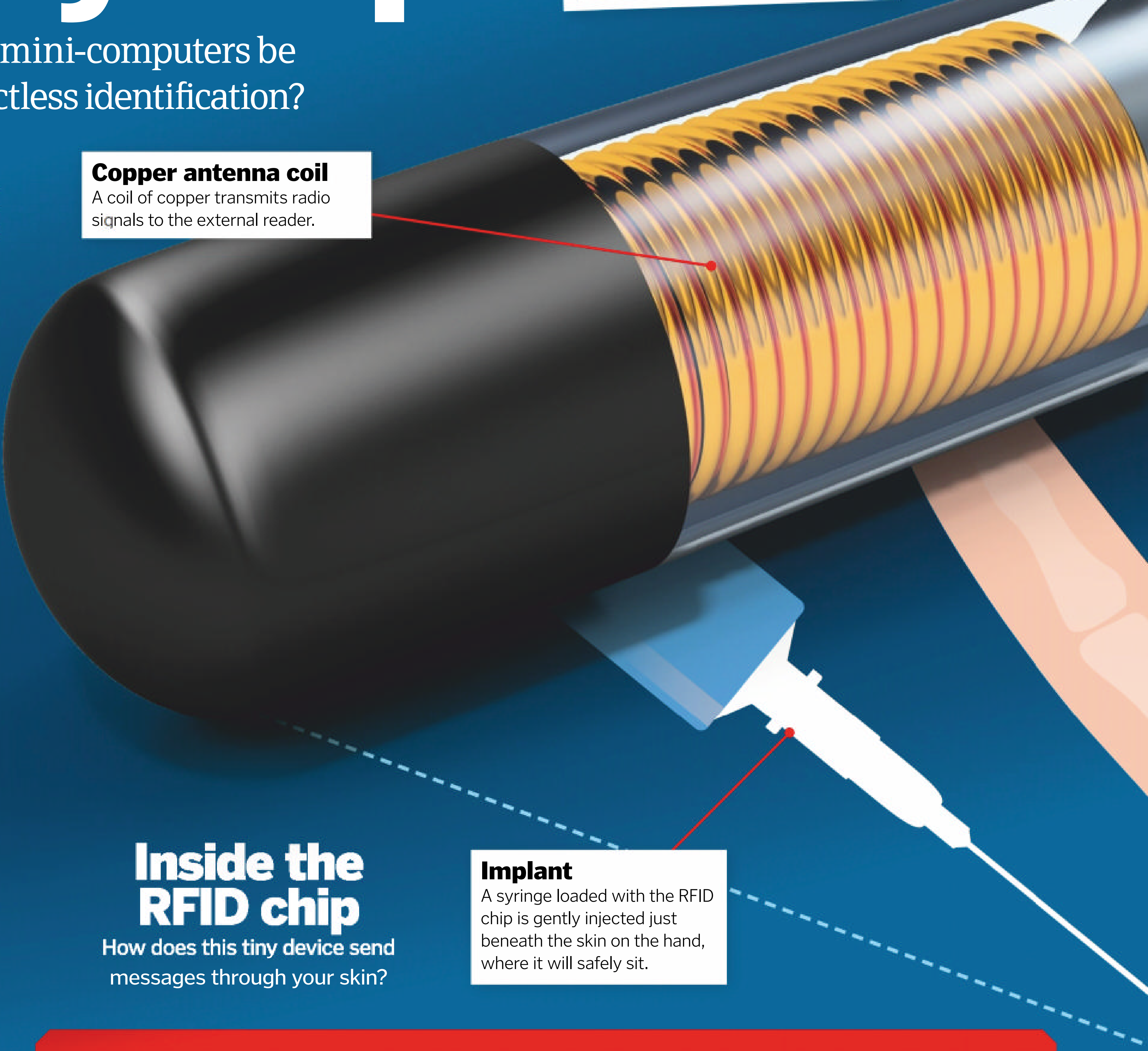
How comfortable would you feel about walking around with an implanted chip encrypted with your personal information? Radio-frequency identification (RFID) is not a recent technological revelation, with the technology developed back in the 1970s. They're most widely used today as the chips implanted beneath the skin of our household pets, placed as tags to track products or used in security passcards. However, in recent years there has been a growing trend making its way beneath the skin of human hands.

RFID technology has allowed for the development of implantable near-field communication (NFC) chips in humans. Within the implantable capsule, each around the same size as a grain of rice, a tiny microchip stores data, waiting to be deciphered by an external reader. When scanned by the reader the internal chip sends radio waves back to the reader, which is then translated into meaningful data. This data can come in the form of security permissions to RFID-locked doors and contactless payments, and has even been suggested for use in Alzheimer's patients to source medical information.

But how close are we to using this technology in our everyday lives? Well, it's closer than you might think. Back in 2017 a tech company called Three Square Market in the US became the first to offer microchips to its staff as a way to replace the commonly used security cards. 50 workers reportedly underwent the procedure, allowing them not only to open doors but also access computers and even purchase food and drinks.

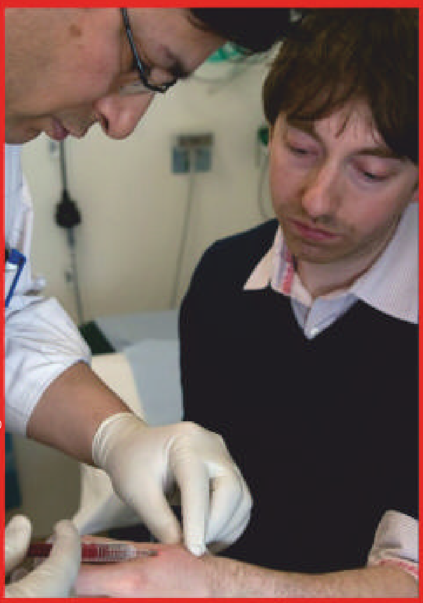
## Inside the RFID chip

How does this tiny device send messages through your skin?



**Copper antenna coil**
A coil of copper transmits radio signals to the external reader.

**Implant**
A syringe loaded with the RFID chip is gently injected just beneath the skin on the hand, where it will safely sit.



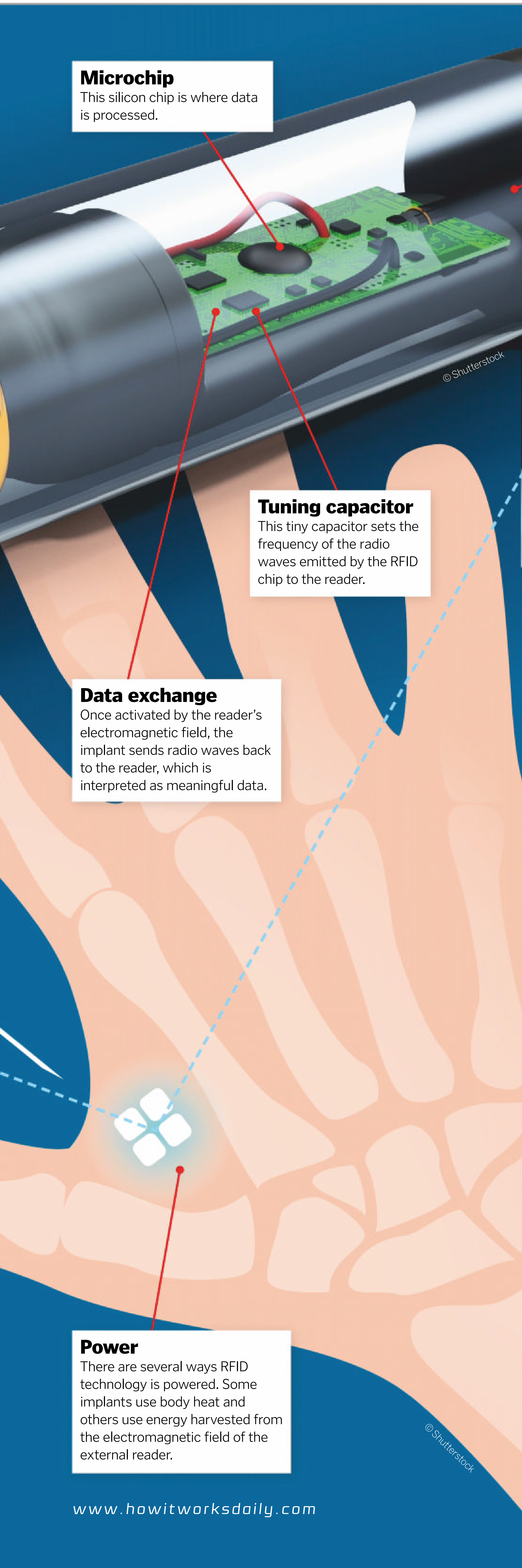
Source: Wiki/Paul Hughes

Dr Mark Gasson had his RFID chip implanted back in 2009, before hacking it with a computer virus

## Digital virus

**The human body is typically well equipped to tackle infection by various viruses thanks to our complex immune system. However, by embedding technology such as RFID chips beneath the skin, could we be inadvertently inviting the possibility of another kind of virus infecting our bodies? With the ability to hold only two kilobytes or so of data, there's not much room to store antivirus or protection software to stop hackers from stealing the chips' entrusted information. Simply standing close to an implanted hand with a reader could collect data, unbeknownst to the owner, a fear also expressed in recent years about contactless card payments. However, back in 2010 a researcher at the University of Reading purposely hacked his implanted RFID chip to house a piece of malware, making him the first human to be infected with a computer virus. Although of course this virus bore no effect on his biological health, the virus could be passed onto the external readers.**

**DID YOU KNOW?** *About 3,000 people in Sweden have inserted a microchip into their hand*



**Microchip**
This silicon chip is where data is processed.

**Capsule**
The internal mechanics of these chips are held in a silicate glass, which is a biocompatible material, beneath the skin.

**Tuning capacitor**
This tiny capacitor sets the frequency of the radio waves emitted by the RFID chip to the reader.

**Data exchange**
Once activated by the reader's electromagnetic field, the implant sends radio waves back to the reader, which is interpreted as meaningful data.

**Power**
There are several ways RFID technology is powered. Some implants use body heat and others use energy harvested from the electromagnetic field of the external reader.

© Shutterstock

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Implanting an RFID chip is similar to having a body piercing, tattoo artists being one of the common professions administering the device

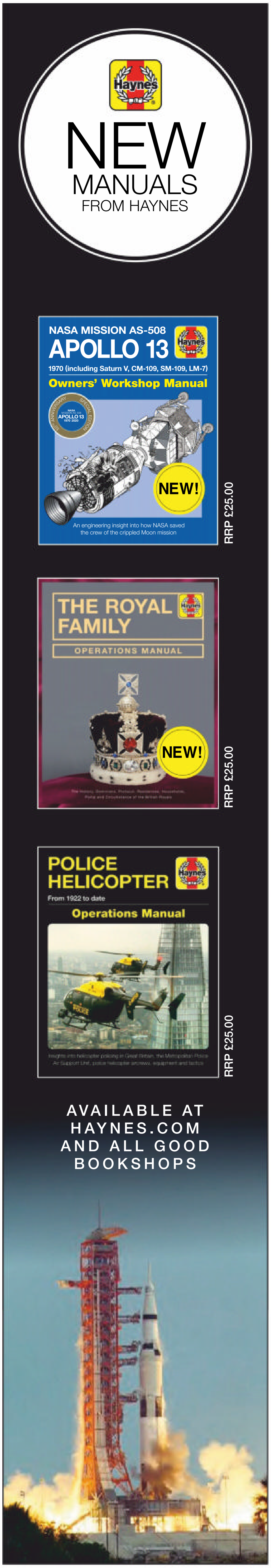
© Getty

## Project Cyborg

**Taking RFID technology and applying it to human modification became reality in 1998 when British engineer Professor Kevin Warwick and his team at the University of Reading created the first 'cyborg'. Using himself as the first test subject to receive an RFID implant, 'Project Cyborg' saw Warwick undergo a surgery whereby a silicon transponder was placed in his forearm. The newly implanted chip allowed Warwick to walk the halls of the cybernetics department and access doors with ease using the unique signature of the signal emitted by the chip beneath his skin. Taking the implanted technology one step further, in 2002 Warwick underwent a surgery that implanted a 100-electrode array in the nerves of his arm, allowing Warwick to control a wheelchair and an artificial hand. Warwick's controversial experiments paved the way to understanding how the human body responds to implanted technology and its future applications.**

© Shutterstock

Professor Kevin Warwick conducted a series of cybernetic experiments on himself



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# Bomb-disposal suits

How this armour protects the technicians who disarm explosives

Bomb-disposal suits are a form of specialised heavy body armour used by weapons specialists when diffusing explosive devices. They are used primarily by the military, but also see action in police forces. Their main role, unsurprisingly, is to protect the wearer should the bomb unexpectedly detonate.

The suits are designed to mitigate the effects of intense heat, pressure and fragmentation – the debris from a bomb that flies off at high speed. This protection is achieved by combining several high-strength but low-weight materials such as Kevlar, Nomex, foams and a range of plastic composites, each layered and mixed to provide an all-round barrier to the effects of a blast.

As well as shielding the wearer, these Advanced Bomb Suits (ABS) are also responsible for keeping them connected to their team and as comfortable as possible. These factors are critical when out in the field, as often conditions can be extreme – such as in hot climates – and bomb disarmament is a very stressful operation. Built-in communication and ventilation systems ensure the technician stays informed and cool under pressure respectively.

Over the past decade or so bomb-disposal suits have been in increasingly high demand, primarily due to the conflicts in Iraq, Syria and Afghanistan. This said, remotely controlled robots are now being used more and more to help avoid human casualties.

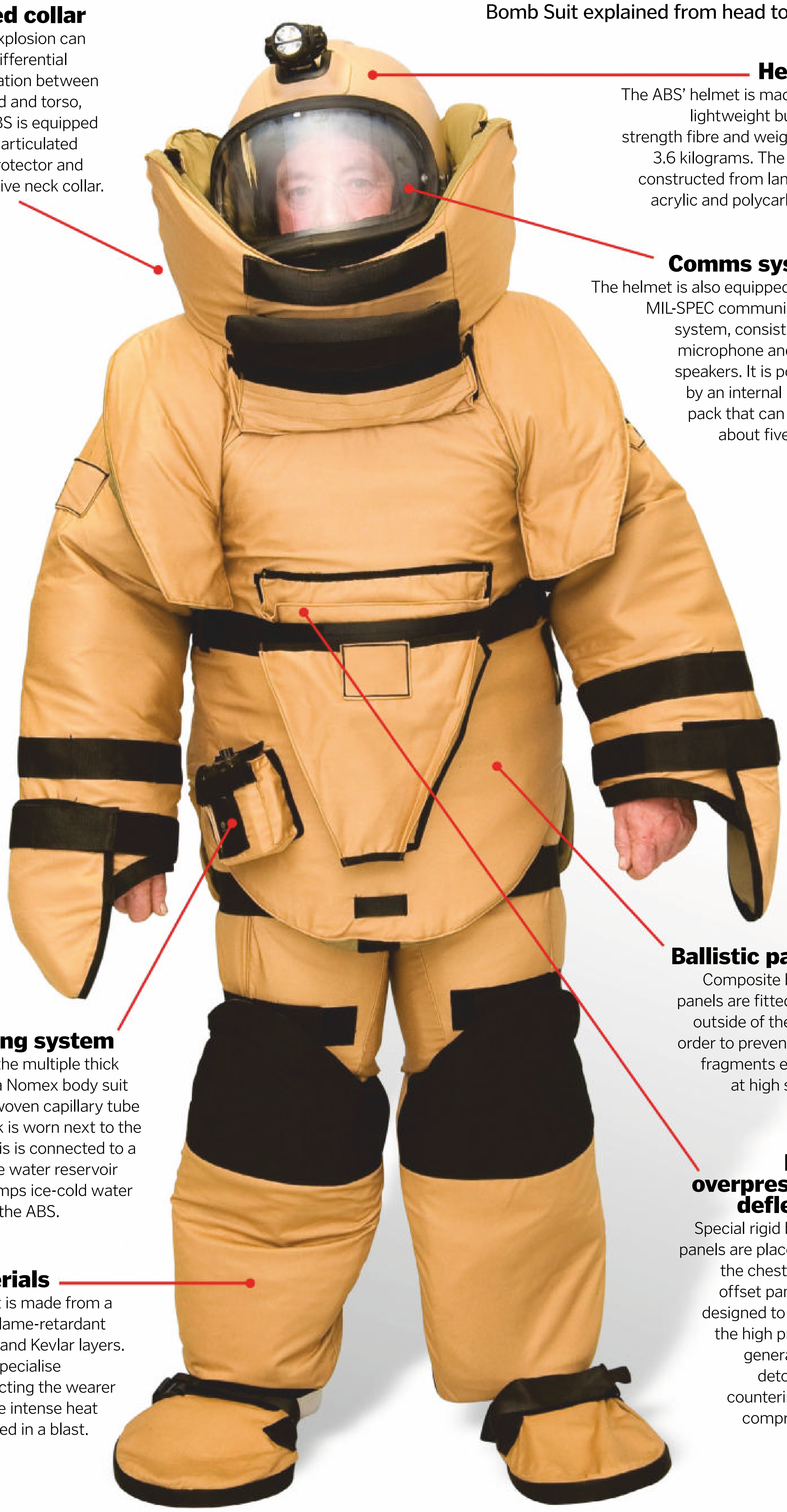
## The history of disarming bombs

**The earliest references to bomb disposal stem from World War II in England. Nazi Germany had undertaken a large bombing campaign against Britain, and a number of the devices that were unleashed landed but failed to detonate. It caused a spiked increase in civilian deaths, with unexploded bombs accidentally being triggered during peoples' day-to-day lives.**

**This led the British government to begin training volunteer members of the public in bomb-disposal techniques, with groups tasked with clearing sites laden with buried and undetonated weapons. Unlike bomb-disposal units today, these civilians wore no protective clothing and had only very basic tools, having to make do with spades, axes and wire cutters.**

## Anatomy of the ABS

The materials and tools of the Advanced Bomb Suit explained from head to toe



**Raised collar**
As an explosion can cause differential acceleration between the head and torso, each ABS is equipped with an articulated spine protector and supportive neck collar.

**Helmet**
The ABS' helmet is made from lightweight but high-strength fibre and weighs only 3.6 kilograms. The visor is constructed from laminated acrylic and polycarbonate.

**Comms system**
The helmet is also equipped with a MIL-SPEC communications system, consisting of a microphone and set of speakers. It is powered by an internal battery pack that can last for about five hours.

**Ballistic panels**
Composite ballistic panels are fitted to the outside of the suit in order to prevent bomb fragments entering at high speeds.

**Cooling system**
Due to the multiple thick layers, a Nomex body suit with a woven capillary tube network is worn next to the skin. This is connected to a two-litre water reservoir that pumps ice-cold water around the ABS.

**Lung overpressure deflector**
Special rigid ballistic panels are placed over the chest. These offset panels are designed to absorb the high pressure generated on detonation, countering lung compression.

**Materials**
The suit is made from a mix of flame-retardant Nomex and Kevlar layers. These specialise in protecting the wearer from the intense heat generated in a blast.

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# BRAIN DUMP

Because enquiring minds need to know...

## MEET THE EXPERTS

Who's answering your questions this month?

MARK SMITH

ANDY EXTANCE

ANDREW MAY

## Why are beavers' teeth orange?

**Janice Myers**

The same reason that blood is red and rust is brown: iron. Humans and many other animals make their teeth out of an enamel material that contains magnesium, which looks whitish. Beavers have iron in their enamel instead, which gives it more of a red colour. Iron makes beavers' teeth stronger, which is why they can use them like a power tool. It also protects them better against tooth decay from acid released by bacteria. **AE**

Beavers have red teeth because they contain iron, which makes them stronger

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## Want answers?

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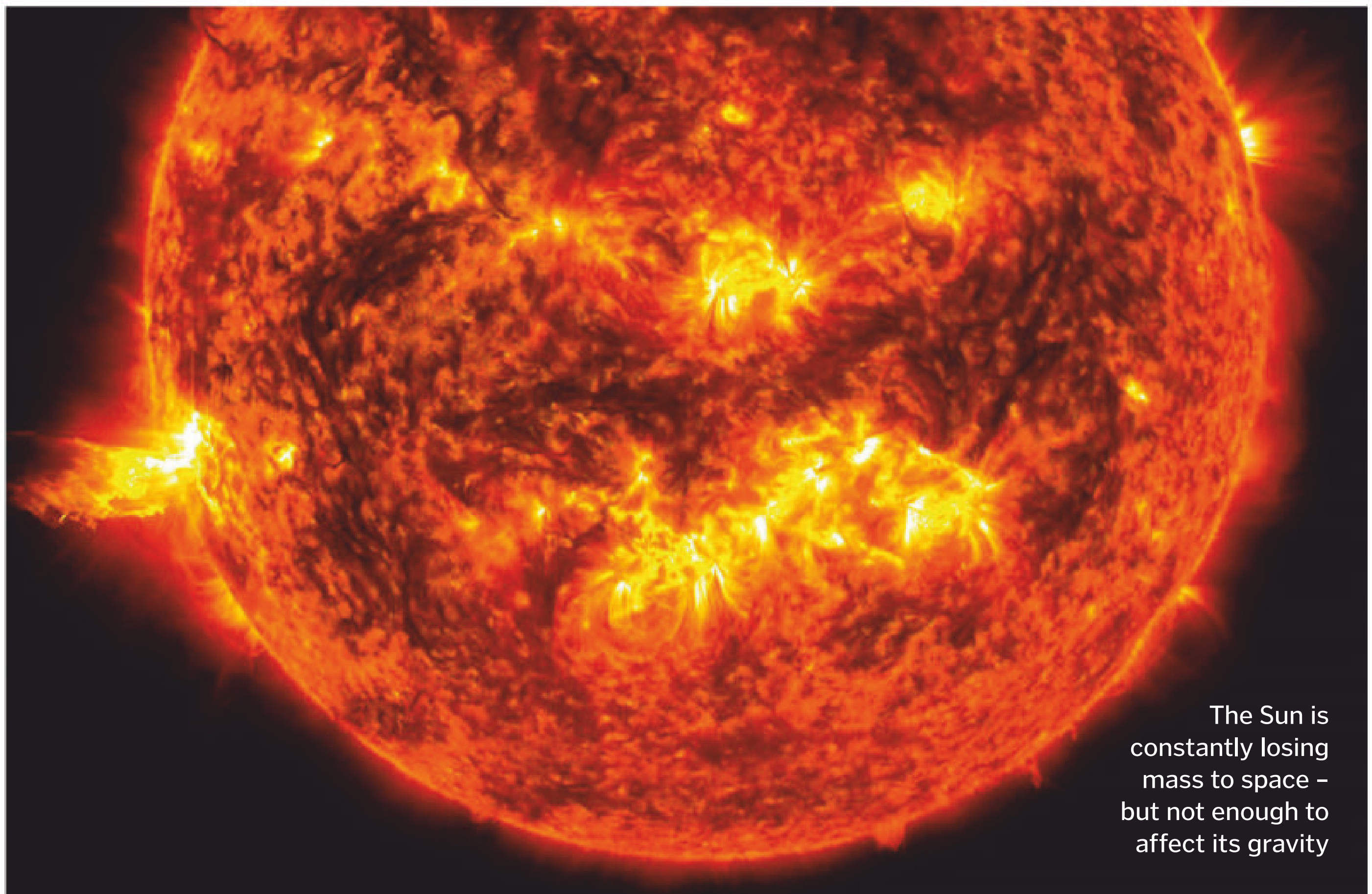


The Sun is constantly losing mass to space – but not enough to affect its gravity

© NASA

# If the Sun is constantly losing mass, will the outer planets eventually fly off into space?

**Olivia Stevens**

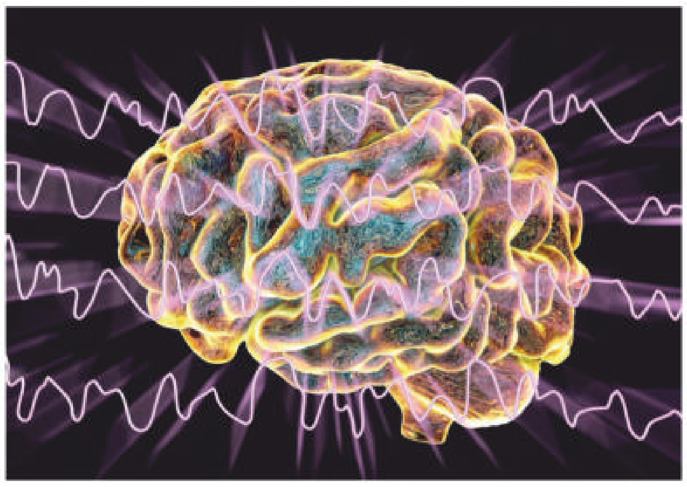
■ It's true that the Sun is losing mass, both directly through the solar wind and indirectly through the conversion of mass into radiated energy via nuclear fusion. It's also true that the only thing holding the planets in their orbits is the pull of the Sun's gravity, which gets weaker as it loses mass. But the loss rate is so small in relation to the Sun's total mass that it can be ignored in practice. In a million years the orbit of Neptune – the outermost and least tightly bound planet – will only have increased by about 40 metres. **AM**

© Getty

# Why are there so many species of fungi that are poisonous to humans?

**Amir Lopez**

■ Mushrooms don't just have it in for humans – they're poisonous to many animals. It's likely so they avoid getting eaten before they can release spores that will form the next generation of fungi, as animals have evolved to stay clear of this deadly meal. **AE**



© Getty

# Do bigger brains among humans mean more intelligence?

**Jay Russell**

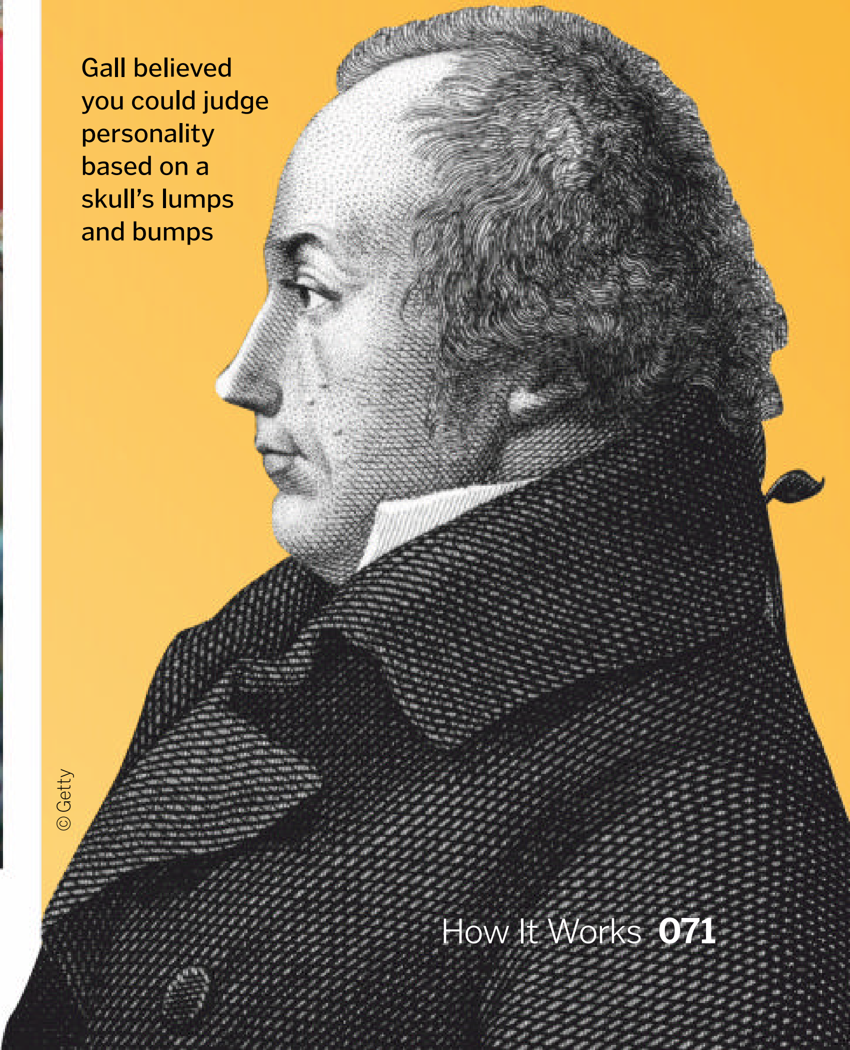
■ Brain size isn't a good predictor of intelligence, which depends on how effectively information is passed around inside the brain. This depends on many other factors besides actual physical size. **AM**

# What was phrenology?

**Mark Burns**

■ Phrenology was the belief that you could make judgements about someone's personality or mental health simply by measuring the lumps and bumps on their head. Regarded as a pseudoscience, it began in Vienna in the late 1700s and was the brainchild of German doctor Franz Joseph Gall's theory of 'organology'.

Although now debunked, Gall's assumption that character and emotions are located in specific parts of the brain is considered an important historical advance towards neuropsychology. **MS**



Gall believed you could judge personality based on a skull's lumps and bumps

© Getty

Driving on the left dates back to when we needed our right hand to fight

© Getty

# Why do Britons drive on the left side?

**Hannah Elliot**

Way back before cars were invented in Britain, roads were used for horses and carriages. If it became necessary for you to have a sword fight on the road – say, with a rival knight – you'd have to draw your sword. Because most people are right-handed, it made more sense to ride on the left side of the road so you could fight with your right hand.

Today British people still drive on the left, and about 35 per cent of other countries around the world do too – but they are mostly former British colonies. Meanwhile, the rest of the world drives on the right. **MS**

## How many galaxies are in the universe?

**Kelly Valdez**

It's impossible to count them all, but what astronomers can do is count the number of galaxies in a relatively small volume of space and then extrapolate this to the volume of the entire observable universe. This gives a total figure of between 200 billion and 2 trillion galaxies. **AM**

© NASA/ESA

© Getty

## Why does the soap tray of a washing machine smell like eggs?

**Douglas Rogers**

If the smell is just coming from the soap tray, that means it probably needs a good clean because something's living in it! Bacteria and fungi like mould enjoy dampness, and any leftover washing powders and liquids give them something to eat. Some of these bacteria release hydrogen sulphide, which can cause a nasty eggy smell. **AE**

© Getty

Gas pipelines, such as this one, are also sometimes seen above ground

## Why do you see pipes running above the ground in Russia?

**Liam Bouchard**

Oil pipelines are often built above ground in areas of permafrost – permanently frozen ground – not just in Russia but in places like Alaska and Canada too. The problem isn't that the pipes would freeze, because they're heated to 60 degrees Celsius to keep the oil flowing. But if such a hot pipe was buried in permafrost, it could melt the ice and cause the ground to collapse, possibly breaking the pipe. **AM**

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# Why can't we remember everything, like a computer drive?

**Carl Bennett**

Our brain memory isn't much better than an 8GB USB storage device, but every day we consume around 34GB of data. We can't 'expand' our memory the way a computer can with cloud storage or bigger hard drives, so some of it has to be let go. **MS**

**Want answers?**

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# What is a Humvee?

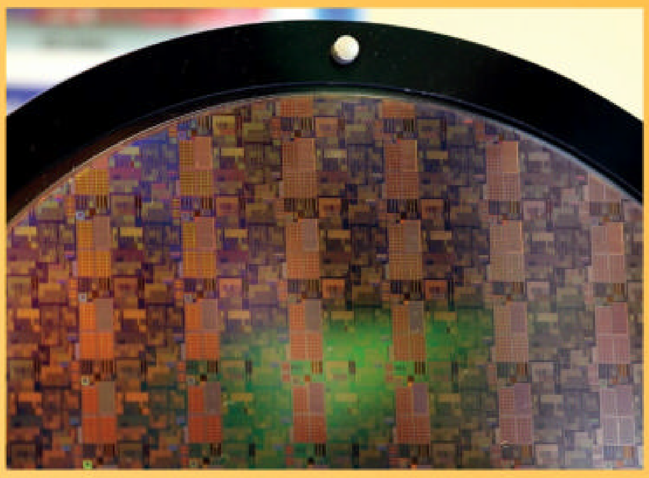
**Debra Bell**

The High-Mobility Multipurpose Wheeled Vehicle, or HMMWV, was developed by the US Military as its frontline tactical vehicle. Over time some of these vehicles have also been bought by private owners. **MS**

# What's the smallest transistor size possible?

**Patricia Morgan**

The answer to this question is always shrinking. Scientists and engineers love limits, because they can push past them! Transistors are extremely small, in the scale of nanometres. The full stop at the end of this sentence is around 300,000 nanometres across. Today's smallest transistors have parts as small as seven nanometres. Overall they're about 54 nanometres high and wide. In 2016 people said transistors with five-nanometre parts would be the smallest possible. At that size, strange physics effects stop them working properly. Since then Samsung and another company have said they will make transistors with three-nanometre parts. **AE**



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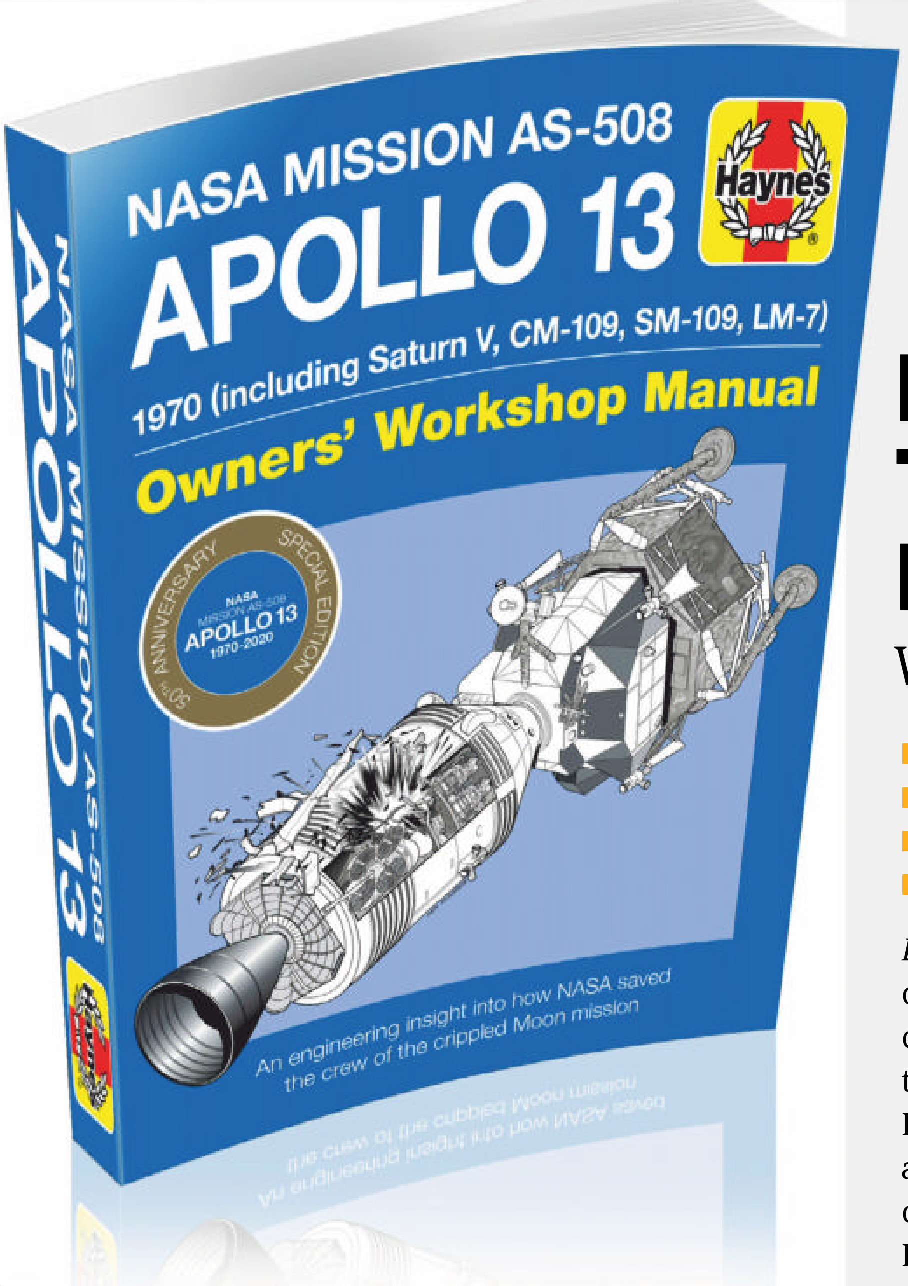
Today's smallest transistors have parts as small as seven nanometres, but that will shrink further

# BOOK REVIEWS

The latest releases for curious minds

## Apollo 13 Owners' Workshop Manual

It's back: a 50th-anniversary reprint with all-new content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50th ANNIVERSARY SPECIAL EDITION
NASA MISSION AS-508 APOLLO 13 1970-2020
An engineering insight into how NASA saved the crew of the crippled Moon mission
NASA MISSION AS-508 APOLLO 13

- Author: **David Baker**
- Publisher: **Haynes**
- Price: **£22.99 (approx. $28.40)**
- Release: **Out now**

You couldn't really find a more qualified person to write this Haynes manual: author David Baker isn't just any old physicist and engineer; he was actually there in NASA's mission control room in 1970, working on getting the crew of Apollo 13 safely back to Earth. He's also an award-winning journalist who's written well over 100 books on all facets of space science and exploration. Since the first edition of this manual he's clocked up another award from the American Astronautical Society at NASA's Marshall Space Flight Center. It looks like the original 2013 edition is all sold out too, so even if it wasn't Apollo 13's 50th anniversary, this manual is well overdue a reprint.

For Haynes Manual newbies, this is as much a history book as an actual 'owners' manual'. For sure it's festooned with technical sketches, but for every trajectory, circuit board diagram or component blueprint there's at least one dramatic photo from inside NASA's Kennedy Space Center or the spacecraft itself, staring into space. Similarly, Baker has packed his text with an appreciable amount of hard stats. Do you want to know the exact composition of the aluminium foil-coated Kapton film that covered Apollo 13's ablative heat shield? Are you itching to find out the precise timing of the drogue parachute deployment during descent? Don't worry – this manual has got you covered. But none of this technical detail is taken out of a broader historical context, in which Baker describes each day of the second most famous and the most dramatic space mission ever.

You're not going to find anything like this manual anywhere else: it compiles dozens of public domain but hard-to-find images and diagrams with Baker's expertise and unique insight into the mission, which is perhaps why the out-of-print first editions have been changing hands for several times the original RRP online. All of that makes this celebratory 50th-anniversary edition of the Apollo 13 mission – with bonus content – really a must-have for both collectors and space enthusiasts. We don't expect this to hang around in stock for long, so get it while you still can!

★★★★★

> This is as much a history book as an actual 'owners' manual'

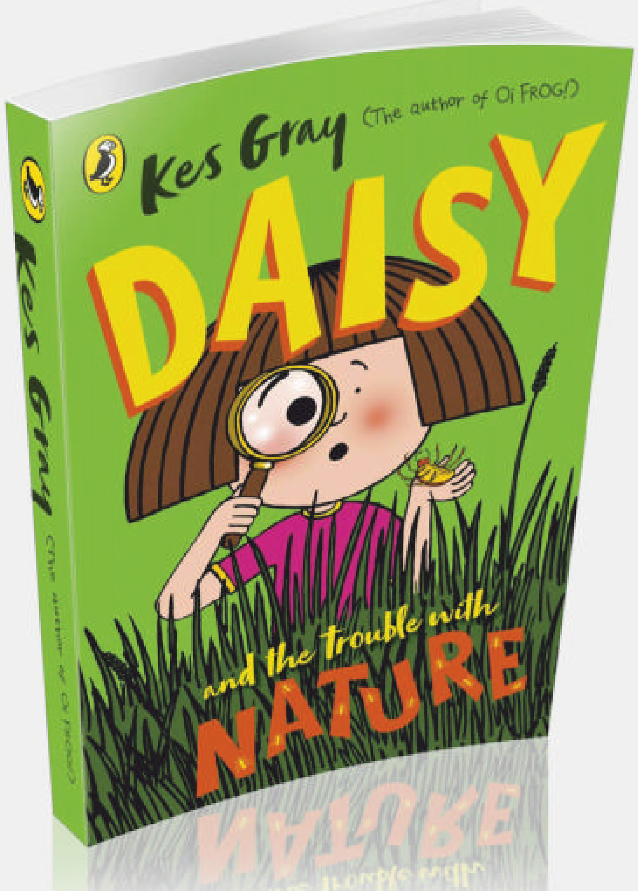
## Daisy and the Trouble with Nature

Where's all the nature?

- Author: **Kes Gray**
- Publisher: **Red Fox**
- Price: **£6.99 / $8.99**
- Release: **Out now**

*Daisy and the Trouble with Nature* follows one rambunctious schoolgirl, Daisy, and her classmates as they try to bring nature to their newly unveiled school garden. Disappointed in the lack of birds, butterflies and wolverines, Daisy and her friends set out to bring nature to a mud-laden garden. During their valiant, albeit turbulent efforts to collect critters to populate their new garden, this book takes its young readers on an adventure to understand nature through the humorous and inquisitive eyes of its characters. Filled with funny illustrations throughout and some interesting facts about wildlife, this book is a great read for children aged between five and seven.

★★★★☆



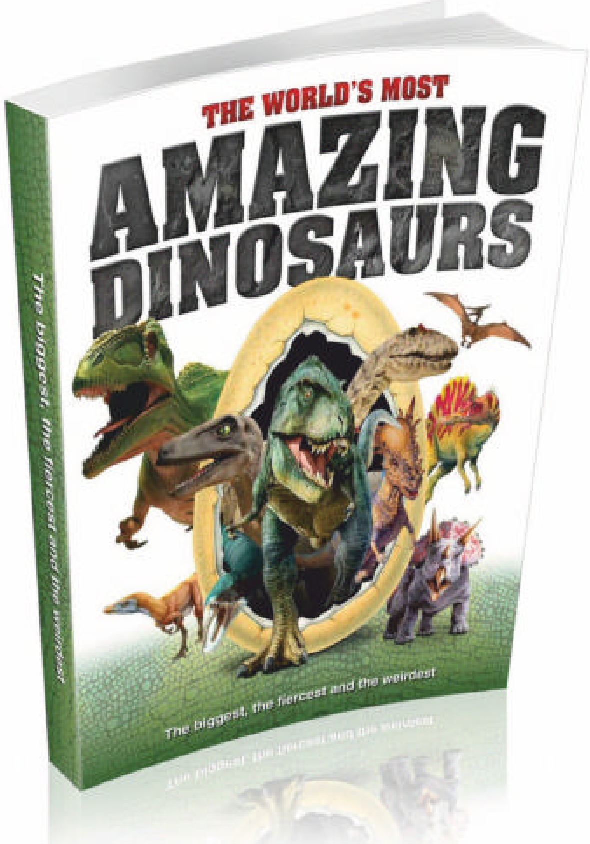
# The World's Most Amazing Dinosaurs

## Earth's prehistoric wonders

- Author: **Various**
- Publisher: **Sona Books**
- Price: **£18.99 / $23.75**
- Release: **Out now**

What does a dinosaur look like? Whether the word instils images of large lumbering beasts, delicate bird-like flyers or long scaly necks, this book is here to prove one depiction doesn't fit them all.

Providing an insight into the varied species that inhabited our planet over 65 million years ago, every page brings these long-extinct characters back to life. The selection of illustrations not only show you what they might have looked like, but are filled with interesting annotations to explain the purpose of the dinosaurs' every feature. Astounding detailing of their colour, texture, internal organs and skeletal structure are presented through cutaway graphics alongside educated opinions from expert palaeontologists.



Can you imagine living alongside this compelling family? Inside, comparative infographics dispersed throughout can help you make sense of what a dinosaur's world was like. How long would a line of taxis need to be to match a dinosaur's length? What is its weight in elephants? How small would we appear standing next to them? In the form of visually pleasing diagrams, all these questions are answered. Giving younger readers extensive yet digestible information, a taste of the past and accounts of impressive discoveries, they can be engrossed in this book of real-life fantasy.

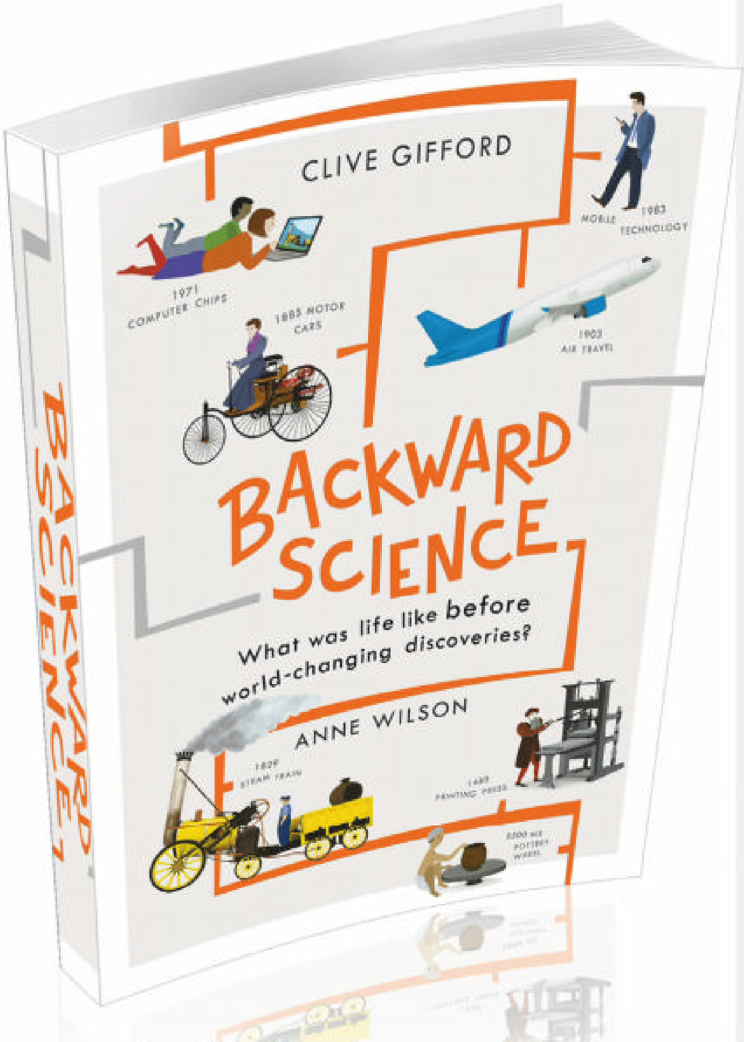
★★★★☆

# Backward Science

## Life before major inventions

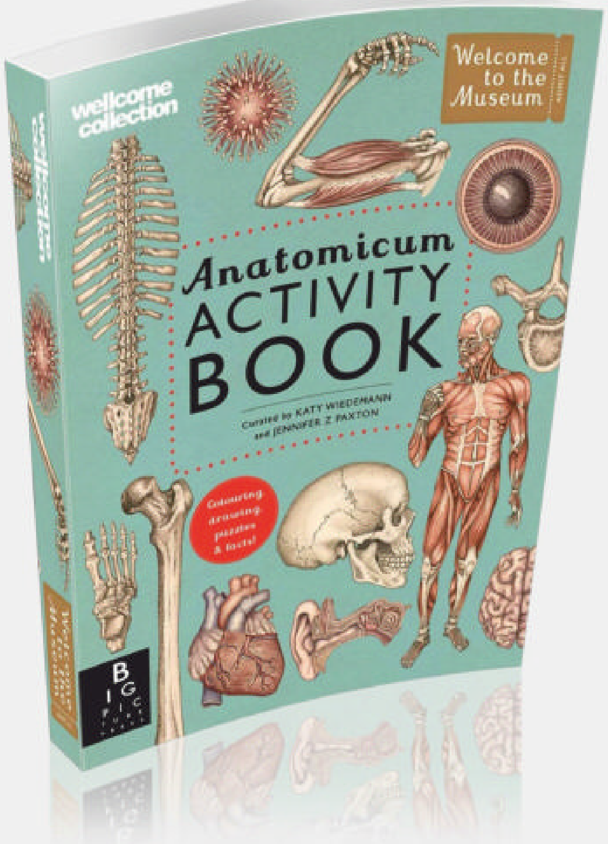
- Author: **Clive Gifford**
- Publisher: **QED Publishing**
- Price: **£12.99 (approx $16.05)**
- Release: **Out now**

We all live in the present. Immersed in our current surroundings, technology and way of life, so it can be easy to take this all for granted. But what would life be like without the ease in which we can contact each other, the comfort we are provided through healthcare or the transport we depend on daily? From complex gadgets to simplistic items such as a toilet to use or paper to write on, all the technology in this book will leave you both thankful for a different aspect of your life and equipped with the historical stories of the people behind them. And as you turn every page, you delve further back in time.



With absorbing illustrations packed with colour, humour and delightful detail, the varied sections can draw the imaginations of everyone in the family back through time.

★★★★☆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# Anatomicum Activity Book

## Colour, draw and solve

- Author: **Jennifer Z. Paxton**
- Illustrator: **Katy Wiedemann**
- Publisher: **Big Picture Press**
- Price: **£9.99 (approx. $12.30)**
- Release: **Out now**

The human body and its overwhelmingly sophisticated composition can be hard to wrap your head around sometimes. However, this activity book seamlessly combines the educational information of a textbook and the fun of a puzzle book. From labelling parts of the lungs and drawing the human eye to a skeletal spot the difference and matching up internal systems, this book is a great way to bring fun into human biology. The real star of this activity book is its illustrations. Both anatomically accurate and beautifully drawn, it almost seems a shame to write on the pages. Filled with interesting facts about the human body and how it functions, this activity book is great for the whole family to enjoy.

★★★★★

> *This book is a great way to bring fun into human biology*

# BRAIN GYM

GIVE YOUR BRAIN A PUZZLE WORKOUT

## QUICKFIRE QUESTIONS

**Q1 Which animal has the biggest heart?**
- ○ Human
- ○ Elephant
- ○ Blue whale
- ○ Giraffe

**Q2 Which of these is not an autoimmune disease?**
- ○ Rheumatoid arthritis
- ○ Type 1 diabetes
- ○ Autism
- ○ Multiple sclerosis

**Q3 How strong is a silverback gorilla's bite?**
- ○ 324 psi (twice an average human's)
- ○ 656 psi (twice a rottweiler dog's)
- ○ 1,250 (twice a great white shark's)
- ○ 1,300 psi (twice a lion's)

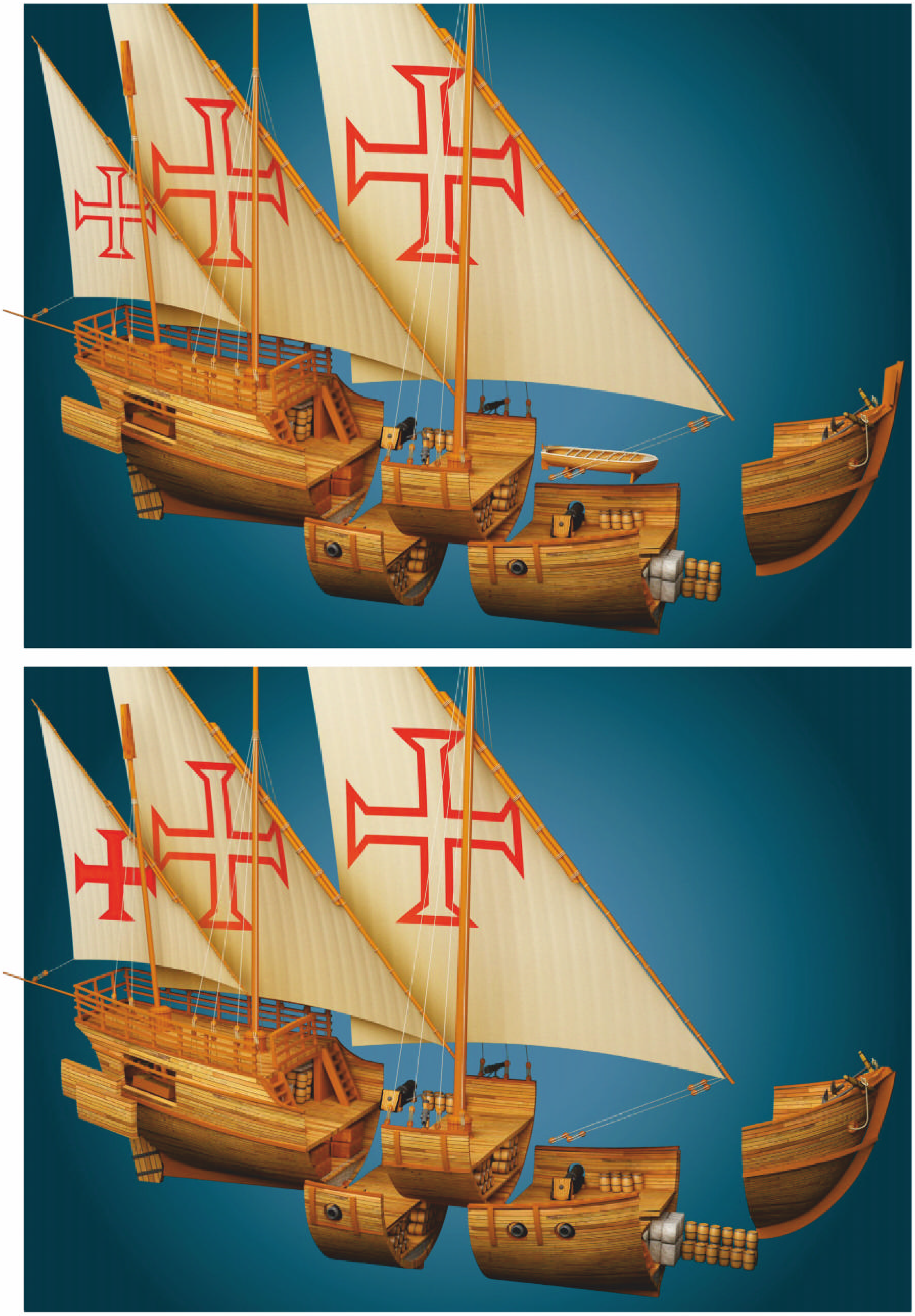
**Q4 Where is the north magnetic pole?**
- ○ Arctic
- ○ Antarctic
- ○ Siberia
- ○ Australia

**Q5 Which Solar System planets have no moons?**
- ○ Mercury and Neptune
- ○ Venus and Mars
- ○ Neptune and Mars
- ○ Mercury and Venus

**Q6 How old was Charles Darwin's tortoise Harriet when she died in 2006?**
- ○ 98 years old
- ○ 117 years old
- ○ 160 years old
- ○ 175 years old

## Spot the difference

See if you can find all six changes between the images below



# Sudoku

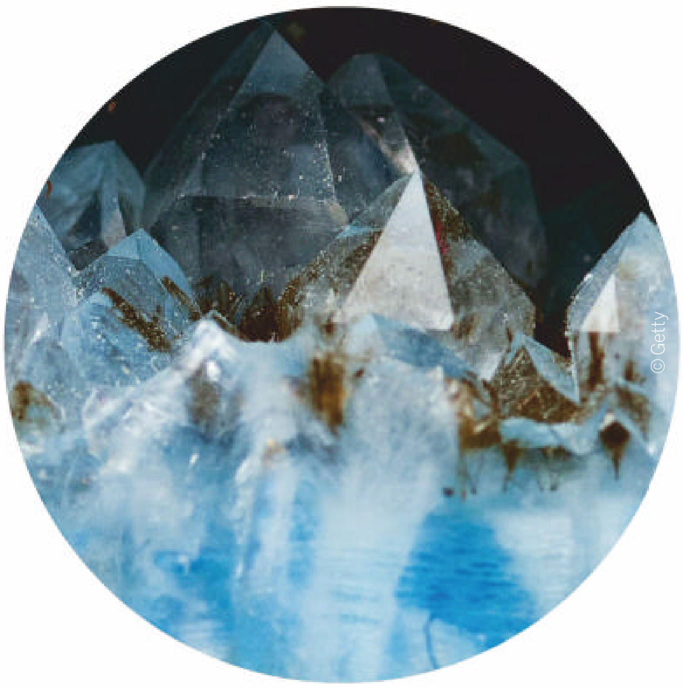
Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9

**EASY**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 8 | 1 | | | 2 | 6 | | 9 |
| | 2 | | | 6 | 8 | 5 | | 1 |
| | | 3 | | | 1 | 8 | 2 | 7 |
| 3 | | | | | 7 | | | |
| 8 | 1 | | 2 | | | | 7 | 4 |
| | | | 9 | 4 | | 2 | | |
| | 5 | 8 | 6 | 7 | | | 9 | 3 |
| 7 | 9 | | | | | 4 | 8 | |
| | 3 | 4 | | 2 | 9 | | 5 | |

**DIFFICULT**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 6 | 3 | | 2 | 1 | | | | |
| | | | 6 | | | | | 1 |
| | | | | | 3 | | 5 | 9 |
| 1 | 5 | | | | 2 | | | |
| | | | | 4 | 5 | | 8 | |
| | 2 | | | | | | 1 | |
| 7 | | | | | 4 | 1 | | |
| | | | | 6 | | 2 | 4 | |
| 5 | | 4 | | | 8 | | | |


© Getty

# What is it?

**Hint:** These rocks sometimes contain hidden treasures

**A** ..............................................................................................

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | A | M | C | P | O | I | B | Q | U | C | E | A | V | Y |
| E | V | I | O | A | E | V | E | R | E | S | T | M | D | I |
| H | T | A | N | G | U | L | L | I | C | V | I | R | U | F |
| E | R | U | E | N | O | R | B | A | U | K | L | X | N | R |
| E | O | C | T | Q | Y | B | O | M | B | P | O | A | I | T |
| V | B | W | O | N | P | N | E | V | E | R | A | L | V | T |
| I | O | E | R | I | V | R | P | N | T | S | L | C | E | W |
| T | T | I | J | E | Z | Z | I | S | T | F | E | H | R | O |
| I | F | G | N | Y | T | W | A | M | H | E | M | I | S | O |
| D | I | N | E | H | R | E | X | J | A | G | L | P | E | R |
| D | H | L | I | A | B | R | O | C | K | T | S | I | P | S |
| A | J | B | D | U | A | G | I | K | C | O | E | S | U | E |
| R | A | E | Z | I | N | T | S | D | O | H | N | A | T | X |
| C | O | R | O | N | A | V | I | R | U | S | I | A | O | J |
| Y | K | P | U | T | U | B | C | I | T | E | N | G | A | M |

# Wordsearch

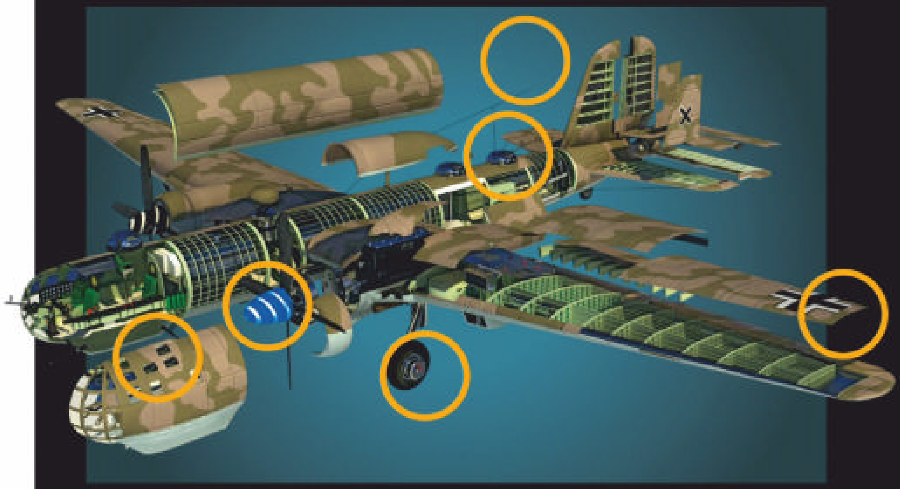
## *FIND THE FOLLOWING WORDS...*

ROBOT
CORONAVIRUS
DARWIN
CHIP
VALVE
PRIMATE
EVEREST
CONE
ADDITIVE
MAGNETIC
BOMB
UNIVERSE

# Check your answers

Find the solutions to last issue's puzzle pages

## SPOT THE DIFFERENCE



## QUICKFIRE QUESTIONS

**Q1** Femur
**Q2** Holding the sky up
**Q3** The Black Death
**Q4** Oxytocin
**Q5** 500 degrees Celsius
**Q6** 21,287 metres

## WHAT IS IT? ...HUMAN PALM

© Getty

# WIN! A ROOMBA

This month we are giving you the chance to win a Roomba 675 by iRobot. This autonomous vacuum cleaner takes the work out of housework with its dirt-detection sensors

WORTH OVER £299!

For your chance to win, answer the following question:

**How many chambers are there in the human heart?**

a) **Four** b) **One** c) **Ten**

Enter online at **howitworksdaily.com** and one lucky winner will win!

Terms and Conditions: Competition closes at 00:00 BST on 4 June 2020. By taking part in this competition you agree to be bound by these terms and conditions and the Competition Rules: www.futuretcs.com. Entries must be received by 00:00 BST on 04/06/2020. Open to all UK residents aged 18 years or over. The winner will be drawn at random from all valid entries received, and shall be notified by email or telephone. The prize is non-transferable and non-refundable. There is no cash alternative.

# HOW TO...

## Practical projects to try at home

**DON'T DO IT ALONE**

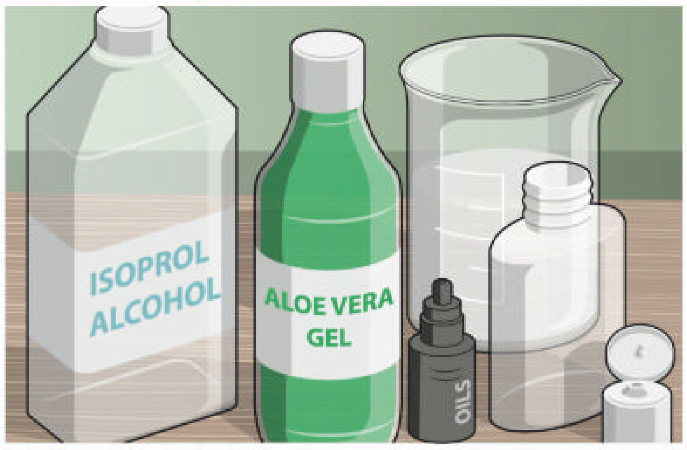
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU

# Make your own hand sanitiser

## Keeping your hands clean is the first line of defence against viruses and bacteria

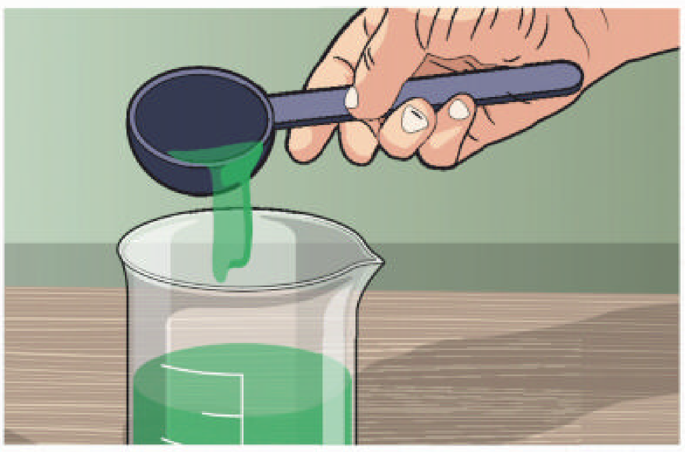
Washing your hands is the best way to keep them clean, but on occasions where there's no soap and water, hand sanitiser can help to kill unwanted germs. With the world becoming disease-conscious, finding hygiene products in shops can sometimes be difficult, so why not make your own?

Making your own hand sanitiser is easy to do and allows you to tailor it to your personal preferences. Follow the steps here to make sure you're protected from disease transmission, wherever you go.



### 1 Collect your ingredients

For this alcohol-based sanitiser you will need: vodka or 99 per cent rubbing alcohol (isopropyl alcohol), aloe vera gel, an essential oil such as lavender, peppermint or cinnamon, a funnel, a spoon, a mixing bowl and a plastic container.



### 2 Add aloe vera gel

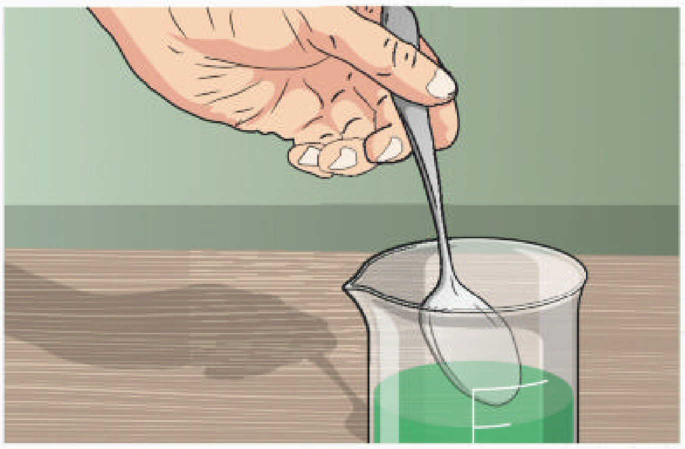
Into a mixing bowl or jug, add one-third of a cup of pure aloe vera gel. Later you can add another spoonful to thicken the mixture to your desired consistency. Ensure all utensils you're using are clean.

### 3 Combine the alcohol

Next add two-thirds of a cup of the alcohol to the aloe vera and mix them together until smooth. The more alcohol you add, the thinner the sanitiser will be – you can always balance it out with more gel if it's too thin.

### 4 Add an essential oil of your choice

Using eight to ten drops, stir each drop into the bowl one at a time. If you would like a stronger scent, add more drops. The oils mentioned in step one contain the best antiseptic properties, but feel free to experiment with different scents.

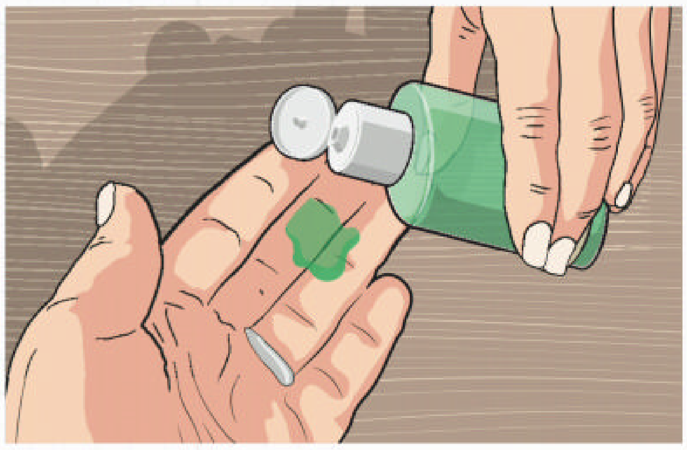


### 5 Mix all your ingredients

With a freshly cleaned spoon, mix the liquid thoroughly until smooth. If any bacteria gets into the mixture it will impact the sanitiser's ability to kill the germs on your hands.

### 6 Pour the mixture into the container

Placing the funnel on top of the container, pour in the liquid until the container is full. Small bottles are ideal for taking with you wherever you go, while leftover sanitiser can be kept in a jar.



### 7 Clean your hands

Your sanitiser is now ready to use. Pour or squeeze the container onto the palm of your hand. You should use enough to cover both hands. Rub the sanitiser into your hands until dry.

© Illustrations by Ed Crooks

**Get in touch**

**Send your ideas to...**

How It Works magazine
@HowItWorksmag
@howitworks@futurenet.com

**Had a go? Let us know!**

If you've tried out any of our experiments – or conducted some of your own – then let us know! Share your photos or videos with us on social media.

**NEXT ISSUE**

See how much bacteria is on your hands

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# INBOX

## Speak your mind...

## Get in touch

If you have any questions or comments for us, send them to:

How It Works magazine @HowItWorksmag howitworks@futurenet.com

Anna and her family used bricks, logs, stones and pine cones to make their cosy bug hotel

© Anna Burrage

The hotel was made following our step-by-step guide and these visuals

## Bug hotel

**Tweet from Anna Burrage:**

**@HowItWorksmag** *Thanks for inspiring us to build a bug hotel! A great afternoon's work with the kids using only garden waste.*

**Response from Edward Crooks (How It Works illustrator):**

*This is so amazing! Every month for the last six years I have illustrated the 'How to' feature of fun kids' activities for* **@HowItWorksmag** *magazine, but rarely get to see people trying it – so it's made my day to see the end results. It looks incredible! Thank you!*

**Thank you Anna for getting in touch to show us this marvellous masterpiece of a bug hotel. In a previous issue of How It Works we gave our readers some steps to follow to create a bug hotel on our 'How to' page. This one has worked out wonderfully, and we hope the children enjoyed seeing the result.**

**Bug hotels are ideal for the minibeasts in your garden. The sections that are shown in this photograph will be perfect for different species to hide and thrive. The stones at the bottom will serve as a cool spot for the likes of frogs, while the loose wood is great for woodlice, spiders, beetles and centipedes. We hope it gets many visitors.**

**Our team loves to see the experiments our readers have tried out, and so does one of our top illustrators, Ed. Yours looks just like his drawings. Great work!**

## Letter of the month

# Heroes unmasked

Hello **How It Works team,**

I just wanted to let you know that our son Hunter, who has been reading **How It Works** for quite a while now, has been busy producing 3D-printed face shields (PPE) at home for the NHS. He first learnt about 3D printing in an article that he read in your magazine last year, so thank you!

He mentioned your magazine in an interview he did with his dad on BBC Radio Bristol this evening, and I thought you might like to know! We have a recording, if you would like to hear it. His dad David, who is now in his (early) 50s, also read your magazine – that is why he started buying it for Hunter, so thank you!

Best wishes,

**Annette Sloly**

**Well done to our nine-year-old reader Hunter, who has been using much of his time at home to support the NHS. The face shields being printed are in high demand at the moment, with hospitals limited in personal protective equipment. These large plastic shields cover the entire face and help prevent hospital workers catching coronavirus while in contact with patients. While we always hope to inspire our younger readers to engage with science and technology, what Hunter is doing is an inspiration to everyone.**

**Thank you for sending us a recording of your radio interview. In the short time of reading How It Works, saving up for your own 3D printer and learning how to use it, you have shown how the real power of these devices comes from the user. Whether you're creating figures for your school friends or life-saving equipment, your acts are truly kind. Thank you Hunter – and keep up the great work.**

**WIN!**

**THE WORLD'S MOST AMAZING DINOSAURS**

*Find out how the dinosaurs survived and thrived, about the mass extinction that ended this era and the fossils these creatures left behind.*

Source: W k/© Ek nk k

Hunter and his family delivered 3D-printed masks to hospitals, where they are sanitised before use

## Magazine crafts

**@STEMyBanda:**

*Some quick craft work before tutoring… Yes they are biology but then all of biology is chemistry which in turn is physics. Plus have lots of* **@HowItWorksmag** *issues on the science of pain.*

**What do you do with your old issues once you have read them? This is one option. Thank you for sharing these pencil pots with us on Twitter. These tins have been decorated with pages from old issues to become something both educational and fun to look at.**

Diagrams and images from the magazine have been reused to decorate pencil pots

© @STEMyBanda

Available in print from all good newsagents and **MyFavouriteMagazines.co.uk**, or as a digital edition for iOS and Android. To enjoy savings on the RRP and to make sure you never miss an issue, check out our subscription offers on pages 26 (UK) and 69 (US).

## NEXT ISSUE…

Issue 139 on sale
**11 JUNE 2020**

# Rainbow of hope

Hi **HIW**,

While we are all being forced to spend so much time at home at the moment, I often look forward to that one exercise outing of the day. For me this is usually a walk around the block. As the days go on I am noticing more and more rainbow drawings in windows and have since seen them on social media. This community spirit gives everyone hope, as they bring a smile to those who need it, but what I want to know is, what makes it a symbol of hope?

Thanks,

**Charlotte Tisdale**

Source: Unsplash/Pam Menegakis

Children are behind most of the rainbow artwork seen in windows

**During the current lockdown situation, children and adults have been creating rainbow images at home. Spreading colour and hope has caught on around the world, but is believed to have been started in Italy a couple of months ago. The success this has had in brightening up people's lives, such as your own, is largely due to the symbolism of the rainbow.**

**In different areas of the world and to different groups, the rainbow takes on varied meanings, but hope is one of the most common. The colours bring brightness to the sky following a storm, and for many the storm and rainbow can represent a difficult time and a more positive ending.**

**As a meteorological phenomenon on Earth, rainbows have been observed since early times. It was discovered that their appearance highlighted the arrival of the Sun after a wet period. From these early days they have been used in ancient religious books and told in legendary tales over centuries.**

## What's happening on…

# social media?

## INSTAGRAM

**On Instagram this month we asked you: what ways are you staying busy and active during quarantine?**

**@lanuthnoe**
*Gardening and jobs around the house… those jobs you keep putting off!*

**@sunnah_safdar**
*Baking, reading and spending time on my balcony in the Sun!!*

**@faaris_haque**
*Learning a new physical and mental skill*

**@hamid.baghernia**
*It's a great time to gain more knowledge. Many online courses can be accessed for free now*

**@ninjamidget81**
*Science experiments in the garden*

© Getty

**@danielj868**
*Playing with my diablo/ Chinese yo-yo in the garden*

**@maia_h3**
*I'm keeping busy by completing a paint-by-numbers picture!*

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# FAST FACTS

Amazing trivia to blow your mind

## E160C

THIS FOOD COLOURING 'E NUMBER' IS ACTUALLY A NATURALLY OCCURRING SPICE: PAPRIKA

## 30.6 GRAMS

MADAME BERTHE'S MOUSE LEMUR IS THE WORLD'S SMALLEST TRUE PRIMATE

## 1.8 MILLION

MILLIONS OF WORLD WAR II BOMBS HAVE BEEN DEFUSED IN BERLIN ALONE SINCE 1947

## 4,200

THE MAXIMUM ALTITUDE A HELICOPTER CAN HOVER AT, DUE TO THE THIN AIR

## 5.5 METRES

SEATTLE IS HOME TO A HUGE MONUMENT TO TRAFFIC CONES

EVEREST'S PEAK IS ENGULFED BY THE FREEZING JET STREAM FOR PART OF THE YEAR

CHARLES DARWIN MADE A LIST OF THE PROS AND CONS OF MARRIAGE, WITH 'MARRY' AND 'NOT MARRY' COLUMNS

## 3.2 KILOMETRES

A BLUE WHALE'S HEARTBEAT CAN BE HEARD ACROSS A HUGE DISTANCE

## 840 CE

OVER 1,000 YEARS AGO, EMPEROR LOUIS OF BAVARIA DIED OF FRIGHT WHEN HE SAW A SOLAR ECLIPSE

## 80

THE APPROXIMATE NUMBER OF KNOWN AUTOIMMUNE DISEASES

STEM CELLS CHANGE INTO OTHER CELL TYPES AND CAN BE USED TO REPAIR TISSUES

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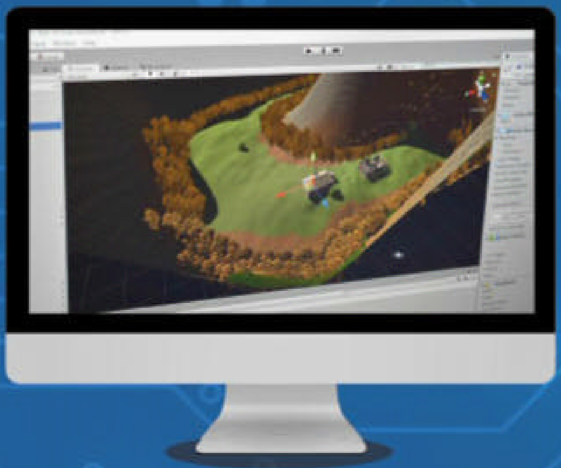
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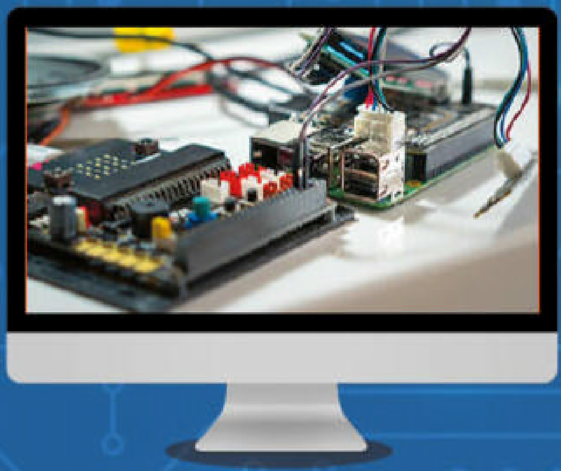
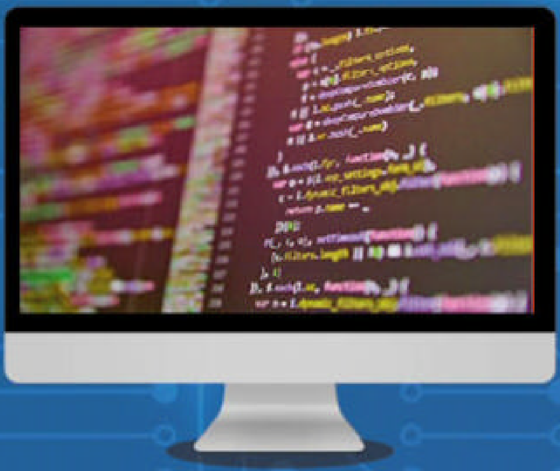
3D CAD

Arduino

Python Programming


Micro:bit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